AERATION OF COTTONSEED IN STORAGE

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CONTENTS

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SUMMARY

Because of problems associated with quality maintenance and germination of stored bulk cottonseed, factors relating to seed moisture content and storage temperatures were studied. Preliminary observations were made to determine the effectiveness of prevalently used systems for moving air through stored bulk cottonseed. Uneven air distribution and high static pressures in the systems contributed to the poor storage conditions.

By moving relatively small amounts of atmospheric air through stored cottonseed, gin processing heat can be removed, minimizing or eliminating mold growth. Aeration, in most cases, can effectively remove any hot spots that may develop during storage from excessive moisture or other causes. Cooling stored cottonseed to a temperature range of 50° to 60° F can help to prevent free fatty acid increases and maintain initial seed viability.

Many originally installed aeration system designs develop high static pressures requiring high power inputs and deliver insufficient amounts of air. With improved system designs and selection of more suitable equipment and operating procedures, stored cottonseed can be effectively cooled with up to 90-percent saving in power inputs.

This publication provides the engineering information necessary for the design and installation of efficient aeration systems for all common styles of cottonseed storages. Sample calculations for equipment selection and system design are included in the appendix.

INTRODUCTION

Cooling cottonseed as it comes from the gin, often at temperatures of 90° to 100° F, and maintaining the stored mass under conditions that will prevent hot spots and moisture buildup are necessary to avoid quality loss. High temperatures encourage mold growth, contribute to poor oil quality by increasing free fatty acid content, and decrease the viability of seed to be used for planting. The most economical means available for maintaining cottonseed at safe temperatures in storage is aeration by an efficient fan and duct system.

It has been common practice for many years to equip cottonseed storages with some mechanical means of moving air through the stored seed, but many of these systems were installed with little reference to engineering principles. The static pressures associated with the different depths of seed and the airflow rates involved must be taken into consideration to achieve an efficient design.

Currently, most air-moving systems use some type of wooden pallet placed over openings in the floor that lead through underground pipes to the fan. In many of these systems much of the static pressure is created in the cottonseed surrounding these pallets. Small-diameter pipes under the floor add to total static pressure loss by carrying air at high velocities (appendix table 6).

High static pressures and high fan speeds do not mean that large amounts of air are being moved or that satisfactory cooling is being obtained. In many old aeration systems, small amounts of air passing through small openings caused a whistling sound, which was considered to denote a good or satisfactory system. Many of these whistling systems are inefficient or in-

capable of cooling the cottonseed properly. System modifications or improvements can provide a more efficient and practical operation, in most cases at lower cost.

Cottonseed storage buildings vary from 40 to 150 ft in width and from 60 to several hundred feet in length. The older buildings are usually of wood frame construction with sheet-metal exterior walls. A few old buildings may have wood floors, but most have concrete floors. Many of the newer buildings have steel framing and sheet-metal exterior walls. Some of the smaller ones are of flat construction (with straight sidewalls and relatively flat roofs), but most of the larger ones have relatively low sidewalls with sloping roofs that reach 100 ft or more in height.

This publication presents engineering data useful in the design of efficient and effective aeration systems, particularly for deep storage, where static pressure (resistance of cottonseed to airflow) is the most important factor to be considered in aeration system design.

The information presented here includes results of over 6 years of study of commercial cottonseed storage. Airflow rates, static pressure measurements, and power unit inputs were recorded for storage with cottonseed depths from 10 to 80 ft and with airflow rates of 2 to 20 cubic feet per minute (ft^3/min) per ton of seed. Prevalently used systems and improved systems were studied, and their operations compared for uniformity of seed cooling in various masses, and for power requirements. Power savings of as much as 90 percent resulted from improving system design.

The information in this report applies specifically to design, equipment selection, and installation for aeration systems in commercial cottonseed storage. The information should be useful to design engineers, equipment suppliers, storage operators, and others who may be involved in designing, selecting, and installing equipment. Storage operators who may want to make their own improvements will find the data on operating procedures of value whether they already have aeration systems or plan to install them.

AERATION SYSTEM DESIGN, EQUIPMENT SELECTION, AND INSTALLATION

Most aeration systems have these principal parts: (1) one or more fans to supply the required amount of air at the necessary static pressure; (2) ducts to move the air into or out of the cottonseed; (3) supply pipes to connect the fans and ducts; and (4) a motor to operate each fan.

Before designing a system and selecting aeration equipment, the following factors should be considered: (1) the size and type of structure in which the system is to be installed; (2) the depth of the cottonseed through which the air will be moved; (3) the desired airflow rate per cubic foot (or per ton); and (4) the quantity of cottonseed to be served by each fan.

After these points have been considered, determinations should be made for (1) total air volume to be supplied; (2) the static pressure against which the fans must operate; (3) the size and type of fan and motor needed; and (4) the type and size of aeration ducts and supply pipes needed.

Types of Systems

Aeration systems for the satisfactory distribution of air and the cooling of stored cottonseed are of two general types, manifold and central duct. The two types will work equally well with stored cottonseed for oil extraction. However, a manifold system is more flexible, making it most suitable for storage of seed for planting.

Manifold system.—In a manifold system one fan can be connected to ducts in two or more storage bins or to a number of ducts in the same bin or compartment. Slide gates or dampers in the supply pipes can be used to control aeration of individual bins.

This system has several advantages for the storage of planting seed. Aeration can be started as soon as enough seed is placed in storage to cover one or two ducts to a significant depth. As additional seed is stored and more ducts covered, additional slide gates can be opened. If an area is not cooling or a hot spot develops, all the gates can be closed except the one to the trouble spot,

and all air directed through that area. Adjustments are also easily made for selective removal.

A manifold system in a storage having a large floor area usually has aeration ducts extending from one side to the other, connected to one or more supply pipes outside the building. The aeration ducts are parallel to each other and spaced a distance not greater than 1½ times the depth of the stored seed.

A manifold system is difficult to adapt to storages of seed for oil extraction in which seed is stored at considerable depths. Unloading may be by portable screw conveyor, front-end loader, or other mechanical device, and ducts on the floor must be removed while such equipment is in use. For some planting-seed storages, it may be practical to build ducts into the floor. However, this type of construction would be prohibitively costly for most oil mill storages.

Manifold systems may result in inefficient use of a relatively large fan and motor unless all units of the system are being aerated. Also, there is usually some loss in air pressure around the slide gates or dampers in the supply pipes, and loss of pressure by friction in a long manifold reduces the volume of air delivered by the fan.

Central duct system.—A central duct system may have one or two large ducts running the length of the storage. Two ducts are necessary when the width of the storage is considerably greater than the depth of the seed. With this type of system, only a short supply pipe may be needed since the fan is located outside one end of the storage. However, the fan may be located at the side of the building with the supply pipe connected to the center section of the duct.

Much larger ducts are used in this system than in the manifold system, since each duct must aerate a larger amount of seed. Airflow rates are usually lower in oil mill storages because of high static pressures developed when cottonseed is 80 ft or more deep. Up to a point, greater compaction also results from increased seed depths, which further increases the static pressure. Therefore, the total static pressure in a deep storage makes it impossible or impractical to aerate at the high airflow rates used in planting-seed storages having lesser depths.

The tunnel in a central duct system serves two functions. It is used for aerating the stored cottonseed, and also for unloading the cottonseed from the storage. A conveyor belt or similar device usually is located in or on the floor of the tunnel. Access to the cottonseed is available through the tunnel, and the seed from all points in the storage is moved into the tunnel by conveying devices or other mechanical means.

This system allows for only limited selection of air movement through any specific part of the storage, although by using tunnel gates or bulkhead doors, parts of the storage can be closed off to increase the airflow rate.

The clear floor provided by a central duct system permits the use of front-end loaders or other mechanical equipment for moving the cottonseed out of the storage. Another advantage of this system is that it avoids the necessity of relocating the ducts on the floor prior to each storage season. Also, once the storage is filled, the fan and motor operate at maximum efficiency.

With this system, once parts of the tunnel are uncovered during unloading, no additional aeration can take place. Neither can aeration and unloading be concurrent, since access to the tunnel is usually necessary for the unloading operations.

Airflow Requirements

Airflow rates given in this report are based on the results of 6 years of research supplemented by industry experience in the major cotton producing areas of Southeast, Midsouth, and Western United States. These rates can be used as a basis for estimating fan and motor sizes and capacities, duct size and spacing, and supply pipe sizes in designing an aeration system for cottonseed.

A designer must recognize, however, that airflow is nonuniform in most aerated storages. This is especially true in Muskogee-type or peak-loaded storages where cottonseed depths may vary from 10 ft at the sidewalls to 100 ft at the peak of the mass. Since air moves along the path of least resistance, the duct should be of sufficient size and in a location (in nonuniform-depth storages) so that the air flows along a semicircular path (fig. 1). Some parts of the cottonseed mass are aerated at a higher airflow rate than others. Therefore, in selecting an airflow rate, consideration must be given to the lowest rate

that can be tolerated in any portion. In deep storages the importance of total static pressure may be increased as a factor in selecting the airflow rate to be used. The portion of seed having the lowest airflow rate determines the time required for satisfactory aeration.

In planting-seed storages, the depth of cottonseed is likely to be more uniform, with a lower maximum. Higher airflow rates are possible and necessary for planting seed; these may be as high as 20 ft^3/min/ton. Rates of not less than 10 ft^3/min/ton or 1/8 ft^3/min/ft^3 are recommended for aerating cottonseed stored for planting purposes. Planting seed has a value 3 to 4 times that of oil seed and more precautions must be taken to preserve its quality and viability. Airflow rates as low as 2 ft^3/min/ton or 1/40 ft^3/min/ft^3 of cottonseed have provided satisfactory cooling in oil mill storage.

Most systems are designed to aerate an entire storage simultaneously. However, in storages having lateral or other multiple duct arrangements with gate valves or dampers, individual parts of the storage may be aerated. However, if the system is designed to aerate the entire storage simultaneously, the time required to cool the whole cannot be decreased by increasing the airflow rate by aerating only a part at a time.

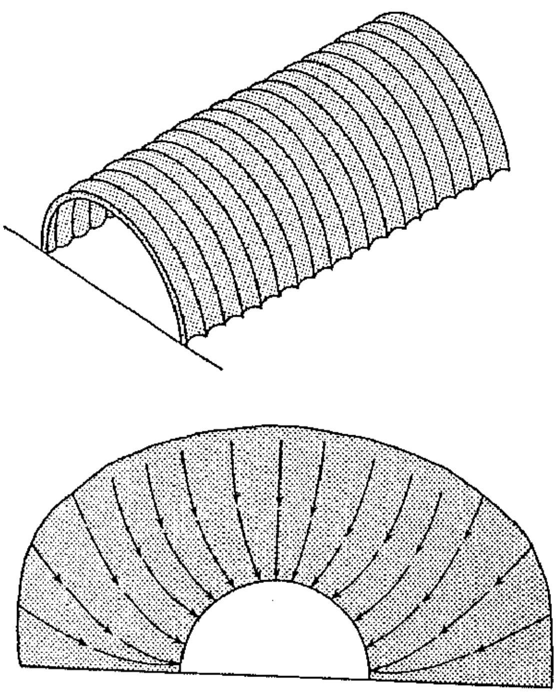

FIGURE 1.—Half-round duct (top) with uniformly spaced perforations permits air to flow from cottonseed into duct with minimum resistance (bottom).

Direction of Airflow

The general practice when aerating cottonseed is to arrange fans so that they draw the air downward through the stored cottonseed, because (1) the natural tendency for air to move upward from the warm cottonseed to the cool upper surface is in part offset; (2) the exhaust air, which is usually warm and moist, is expelled from the warm cottonseed in the lower part of the bin and not through the colder upper surface where some condensation might occur; and (3) the operator can check the condition of the cottonseed by detecting any offensive odor in the exhaust air.

There may be some advantages in changing this practice and forcing air upward through the cottonseed, particularly early in the season. The chief advantage of reversing the direction of flow would be that heat collected under the roof can be forced out rather than being drawn down through the cottonseed. Also, the warmer cottonseed near the surface can be cooled without moving the warm air from under the roof through the cooler cottonseed beneath it. This can shorten cooling time and thus reduce cost.

There are, however, some hazards in using upward airflow, particularly during those times of the year when there is a great difference between day and night temperatures. Moisture from warm air moving upward through the cottonseed can condense in the upper cooled layers. Then this damp layer promotes mold growth and deterioration. Another hazard of upward airflow is that moisture from warm, moist air may condense on the cold roof and drip back onto the surface of the seed.

Fan Requirements

In selecting a fan for aeration, the following must be considered: (1) volume of air to be delivered; (2) the static pressure at which the fan must operate to move the air through the cottonseed and aeration system; and (3) noise level of the fan. The volume of air to be delivered is dependent on the amount of cottonseed to be aerated and the airflow rate desired. Higher air-

flow rates can be used with shallower cottonseed. As the depth of seed increases the total static pressure increases. In deep storages the practical airflow rate may be as low as 2 ft^3/min/ton. The total volume of air to be delivered is the airflow rate per ton times the tons to be aerated.

Static pressures will vary with airflow rate, depth of storage, amount of linters on the seed, and resistance of the aeration system. The resistance of cottonseed is affected mainly by the amount of linters on the seed and by compaction. Research presently underway indicates that compaction does not appreciably increase the static pressure per foot of depth after the depth has reached 45 ft. Airflow rate and depth of cottonseed are the main factors contributing to the total static pressure of any well designed system.

To illustrate, in moving 5 ft^3/min of air per ton through 20 ft of cottonseed, the total static pressure would be approximately 2.75 inH_2O. In comparison, cottonseed 40 ft deep at the same airflow rate, 5 ft^3/min/ton, would present static pressure of over 12.2 inH_2O. Varying the airflow rate also affects the static pressure and power required (table 1).

Static pressures in Muskogee-type or deep storages with cottonseed 75–100 ft deep may be as high as 20 to 25 inH_2O even with airflow rates of 1.5 to 2.0 ft^3/min/ton of seed.

Noise is associated mainly with the type of fan and fan speed. In locations where noise is not a problem, any fan that satisfies the air volume requirements can be used. Propeller and axial-flow fans usually operate at the highest speeds and produce the most noise. Blower or exhaust fans will operate with much less noise. A blower one or two sizes larger than necessary will further reduce the noise level by operating at less than maximum speed to deliver the required amount of air.

TABLE 1.—*Resistance of cottonseed to airflow at specified rates of flow and depth of seed in level storage*

Depth, ft	Airflow, ft^3/min/ton	Static pressure, inH_2O	Power requirement, hp/1,000 tons
20	5	2.75	3.50
20	10	6.40	19.00
20	15	10.60	43.00
30	5	6.50	10.00
30	10	15.75	42.50
30	15	26.50	100.00
40	5	12.25	17.00
40	10	30.50	86.00
40	15	52.50	210.00

Types of Fans

The fans most commonly used for aerating cottonseed are of the centrifugal (radial-flow) type. The propeller (axial-flow) fan may be used where static pressure is not more than 3 to 4 inH_2O. Centrifugal fans must be used to aerate deep storages.

Three types of centrifugal fans are shown in figure 2. The forward-curve fan (fig. 2*A*) has a large number of blades and operates at a relatively low speed; the motor may be overloaded if the static pressure is decreased, causing an increase in air delivery. This type of fan is not recommended for aerating cottonseed when the motor load will vary considerably between the beginning of the season with a partially filled storage and the end of the season with the storage full.

The backward-curve centrifugal fan (fig. 2*B*) is a high-speed fan that usually has 12 blades. It is slightly more efficient than a forward-curve or straight-blade fan. One of its advantages is that it has a self-limiting horsepower characteristic. If an adequate-sized motor is used, and the fan is operating near the point of greatest efficiency, there is no danger of the motor being overloaded.

Figure 2*C* shows a centrifugal fan with straight blades, sometimes called a pressure fan, or, more commonly, an industrial exhauster. This type of fan, widely used in aerating cottonseed, also has some overloading characteristics when static pressure is reduced but will not overload as much as a forward-curve fan. Common practice is to have a slide gate or damper in the supply pipe leading to the fan; the gate is adjusted to maintain a relatively constant static pressure on the fan, depending on the amount of cottonseed being aerated.

Three types of axial-flow fans are shown in figure 3. Basically they are low-pressure fans, but certain designs are suitable for operation up to medium pressure.

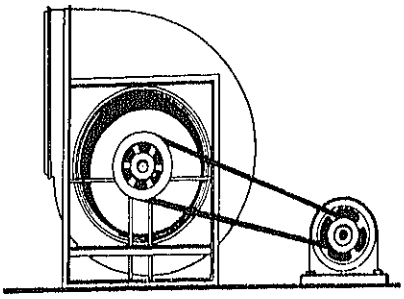

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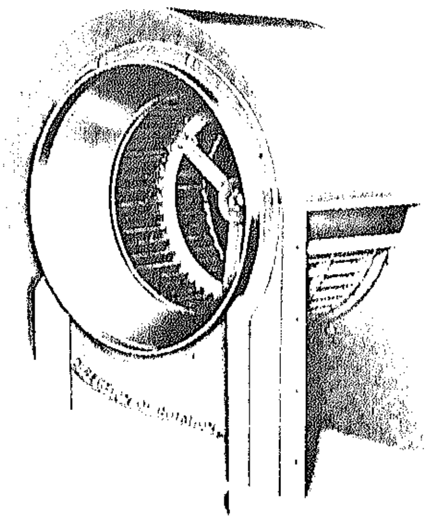
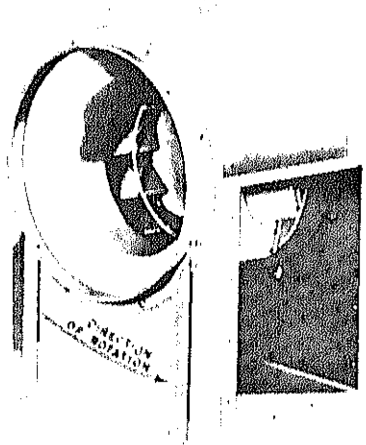
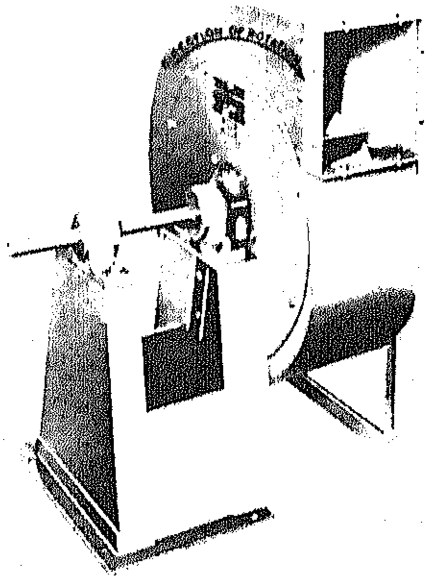
Figure 2.—Centrifugal fan consisting of a fan rotor or wheel within a scroll type of housing. It is designed to move air over a wide range of volumes and pressures (up to 15 inches of water and above). The fan wheel may be equipped with radial tip blades or three other types.



A



B

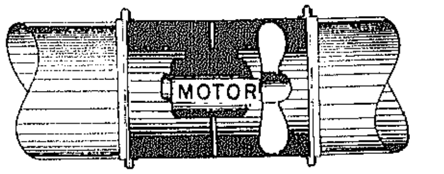


C

A. Fan wheel equipped with forward curve tip blade.

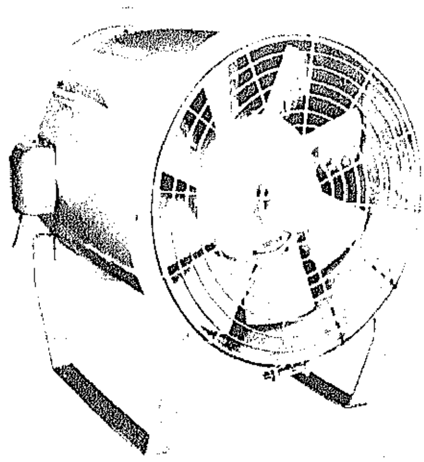
B. Fan wheel equipped with backward curve tip blade.

C. Fan wheel equipped with straight tip blade.

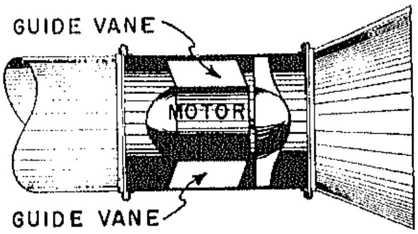


A. TUBEAXIAL FAN

A tubeaxial fan consists of an axial flow wheel within a cylinder. It is designed to move air through a wide range of volume at low to medium static pressures.

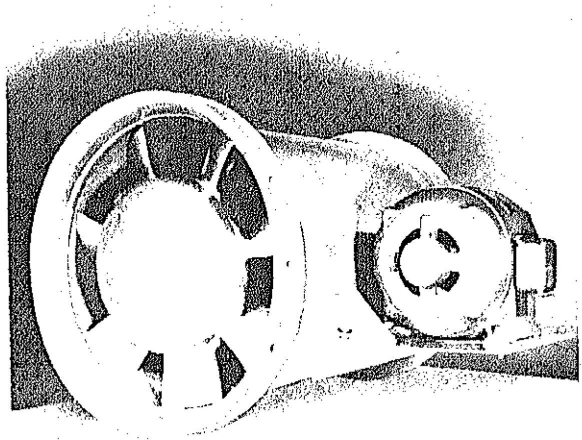


A

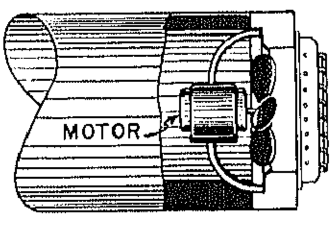


B. VANEAXIAL FAN

A vaneaxial fan consists of an axial flow wheel within a cylinder combined with a set of air guide vanes located either before or after the wheel. It is designed to move air over a wide range of volume and pressures



B



C. PROPELLER FAN

A propeller fan consists of an axial flow fan within a mounting ring or plate. It is designed to move air over a wide range of volume at low static pressures.

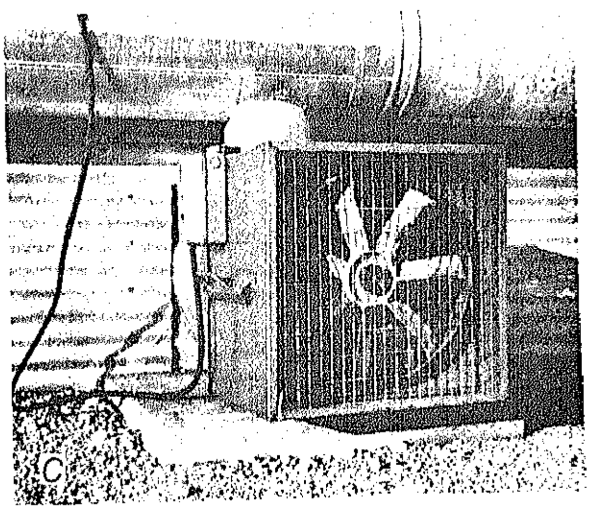


FIGURE 3.—Axial-flow fans.

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The centaxial fan (fig. 4), relatively new in design, is being used in some of the latest aeration systems. The combination design has the characteristics of both the axial and centrifugal fans. The fan housing is cylindrical, with a venturi inlet and guide vanes at the discharge. The fan wheel has airfoil blades which combine the characteristics of the airflow propeller fan and the back-curved centrifugal fan. It has a low noise level and is nonoverloading. This fan offers the installation simplicity of the axial-flow design with the performance of the centrifugal. Its efficiency is very good, and it will perform at pressure ranges up to 16 inH_2O at relatively low speeds.

Fans should be selected on the basis of the performance ratings supplied by the manufacturers, which specify the volume of air delivered by the fans at various static pressures. Reliable performance ratings are assured if the fans are rated in accordance with the testing code of the Air Moving and Conditioning Association.

Fan Connections

No aeration system can perform at its best unless the fan is connected properly. A poor fan connection can reduce airflow by 25 percent or more.

Air should enter the fan in as near a straight line as possible. Short inlet elbows restrict air output (fig. 5). Elbows with a large throat lose less by friction and help to straighten the airflow before it enters the fan. Short elbows on the discharge side of the fan can also restrict flow (fig. 6).

All abrupt changes in pipe size and flow direction can cause reductions in airflow (fig. 7). Standard sheet-metal construction recommendations should be followed for all elbow, transition, and junction fabrication.

Types of Ducts

Ducts may be round, half-round, rectangular, or an inverted V-shape. Perforated floors over a plenum are seldom used for aeration because of

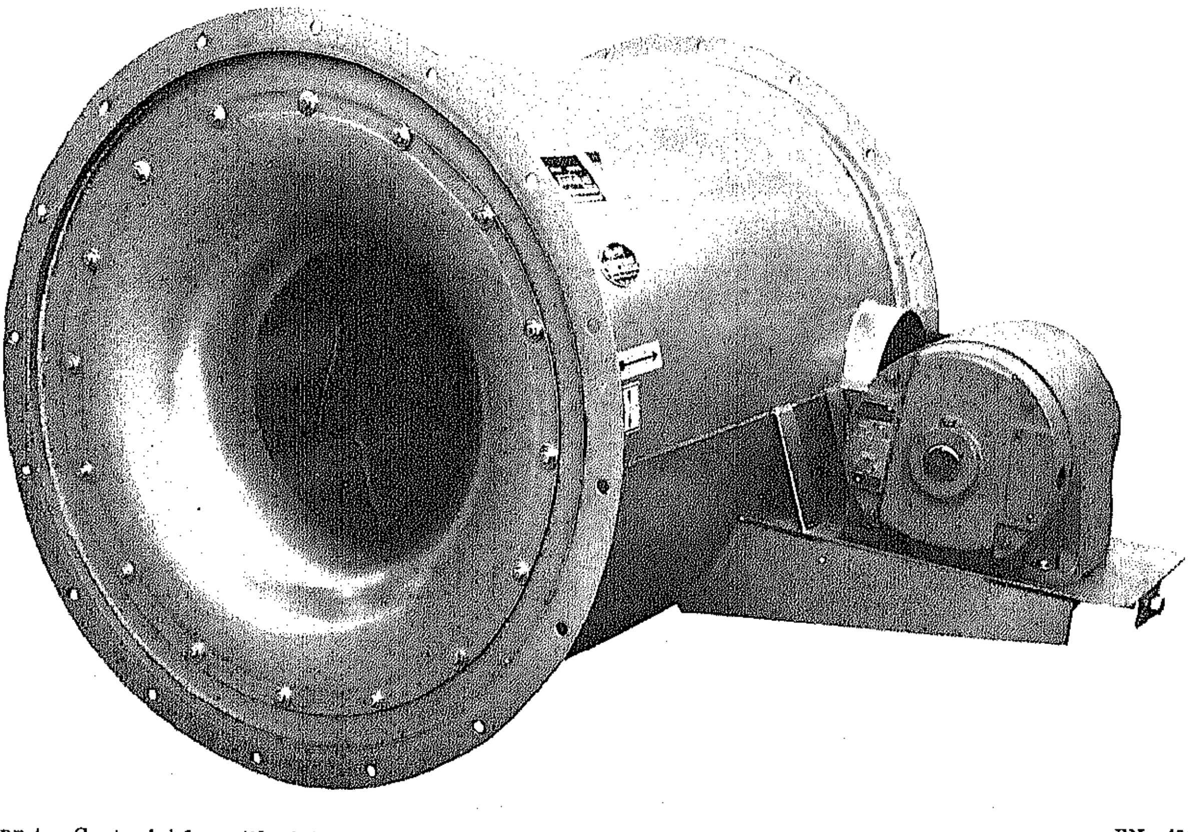

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FIGURE 4.—Centaxial fan with airfoil blades. It will move air through a wide range of volumes at pressures up to 16 inH_2O while operating at relatively low speeds.

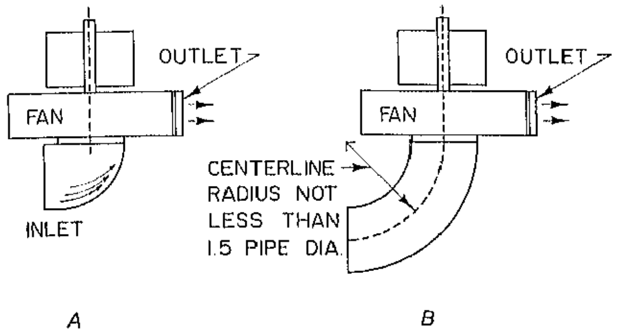

FIGURE 5.—A short inlet elbow (*A*) should be avoided since it restricts fan output; longer elbows (*B*) are better.

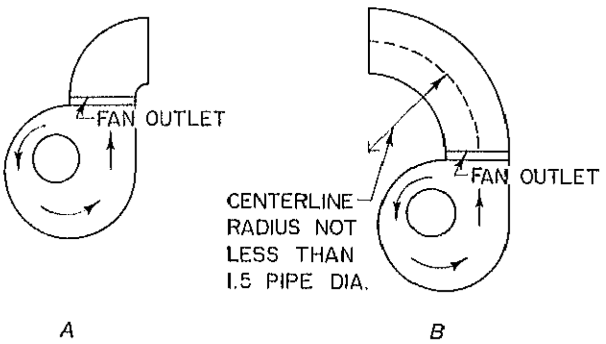

FIGURE 6.—A short elbow attached to a fan outlet (*A*) reduces the fan output. A longer elbow (*B*) is better.

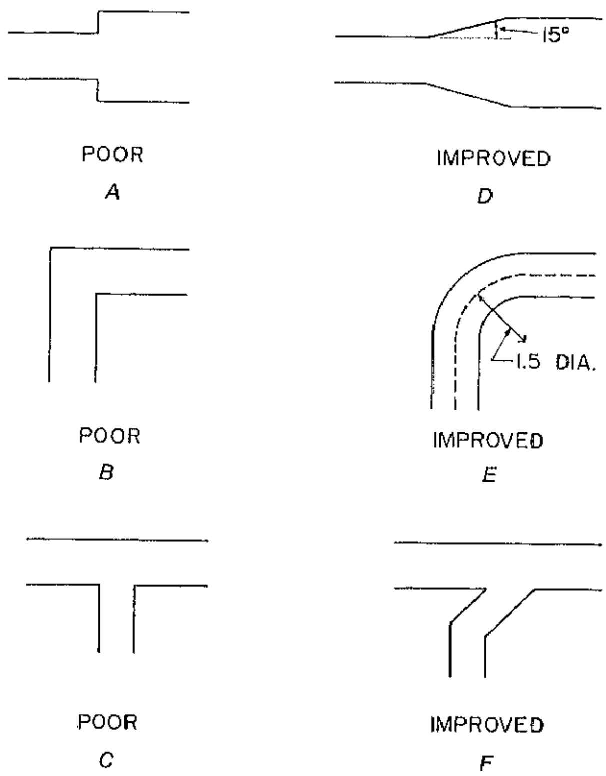

FIGURE 7.—Abrupt changes in pipe size and flow direction reduce airflow (*A*, *B*, *C*). Fabrication by good sheet-metal practice maintains efficiency and reduces pressure loss (*D*, *E*, *F*).

their relatively high cost. Ducts spaced on top of the floor are less costly and have proven satisfactory, although they may produce some nonuniform airflow.

Perforated ducts have openings spaced uniformly over their surfaces to permit air passage through the duct surface. The open surface area should be at least 10 percent of the total duct surface area; 15 percent is better.

Openings must be small enough to prevent the cottonseed from passing through. Round holes up to three-sixteenths inch in diameter will retain normal-size fuzzy cottonseed.

Perforated ducts commonly are made of punched corrugated sheet metal, formed into half-round sections (fig. 8). Flat perforated metal may be used if strengthened with angle iron or pipe inside the duct. These perforated metal ducts may be constructed in sections 2 to 10 ft long to obtain the overall length needed and, at the same time, provide for easy assembly.

Another type of duct is made of 2-by-4 wood members on edge covered with evenly spaced 1-by-4 boards (fig. 9). These ducts resemble perforated ducts in that the air can enter the surface rather uniformly. The spaces between the boards usually are covered with hardware cloth to keep the cottonseed from passing through. These ducts are not as durable as metal ducts.

Tight-wall metal ducts, with one side open and facing downward, are also used as aeration ducts. The inverted V is a commonly used shape. This type of duct has a small equivalent open surface area and is limited to use with small amounts of seed at low airflow rates.

The important dimensions of a duct system are (1) the amount of surface area of the duct, which affects the static pressure losses near the duct; (2) the cross-sectional area of the duct, which influences air velocity within the duct; the length, which affects the uniformity of airflow

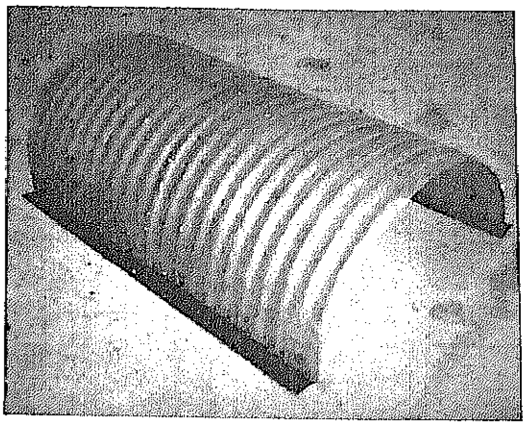

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FIGURE 8.—Semicircular, perforated, corrugated duct with air openings spaced uniformly over the surface. Duct surface area equals diameter squared × length × 0.7854.

through the cottonseed; and (3) the distance between ducts (duct spacing), which influences the distribution of airflow through the cottonseed. Designing an aeration system requires determination of the optimum combination of these variables.

Duct Cross-Sectional Area

The maximum allowable air velocity within a duct determines the minimum duct cross section, which equals total air volume carried in the duct divided by the design air velocity.

$$\frac{\text{Total air volume, ft}^3\text{/min}}{\text{Air velocity, ft/min}} = \text{cross section, ft}^2$$

In most cottonseed storages, an air velocity within the duct of 1,500 ft/min is recommended. Velocities of 2,000 ft/min are permissible in ducts up to 15 ft in length. In most deep storages holding large quantities of seed, the duct cross section will be sufficient when the required surface area for seed aeration is provided.

Duct Surface Area

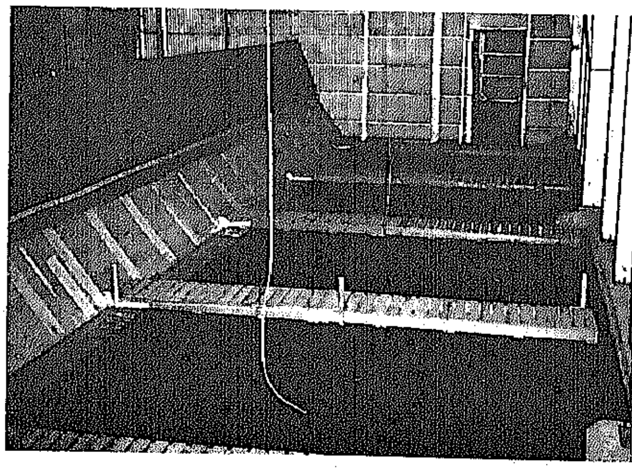
Pressure losses can be held to a minimum by limiting the velocity of the air leaving the cottonseed next to the duct. This velocity is influenced by the amount of surface area in the perforated duct and the airflow rate used. With half-round perforated ducts the air leaves the cottonseed over the entire surface area (fig. 1).

Air velocity should be limited to 10 ft/min through the cottonseed near the duct for seed up to 25 ft deep. In storages deeper than 25 ft, velocities up to 20 ft/min can be used in calculating the amount of duct surface needed.

The total surface area required for a perforated duct can be determined as follows:

$$\frac{\text{Total air volume of duct, ft}^3\text{/min}}{\text{Selected duct surface velocity, ft/min}} = \text{total surface area per duct, ft}^2.$$

A duct that is to handle 800 ft^3/min at a vel-



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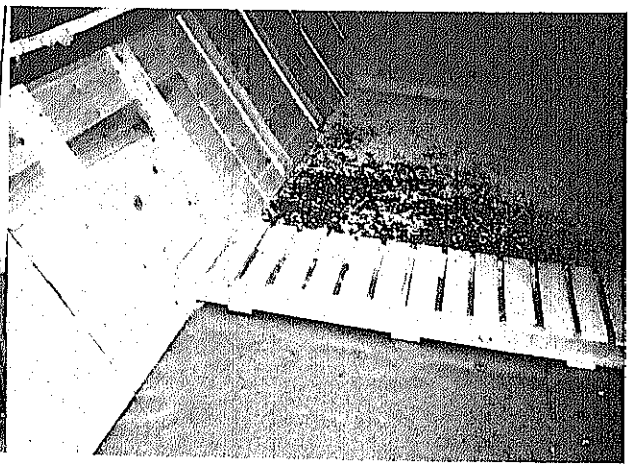

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FIGURE 9.—Ducts constructed of 2-by-4 wood members on edge covered with 1-by-4 boards evenly spaced. Hardware cloth is used to prevent cottonseed from falling through the spaces.

ocity of 10 ft/min, should have a total square foot surface area equal to 800 ft^3/min÷10 ft/min=80 ft^2. Thus a perforated half-round duct 25 ft long requires 80ft^2÷25 ft=3.2 ft^2 of duct surface area per foot length. A perforated half-round duct 24 inches in diameter would meet these requirements satisfactorily (appendix, table 3).

Ducts for Planting-Seed Storages

The design of duct systems for planting-seed storages is most important, since the removal of excess heat from the seed is the prime function of the system. Most planting-seed storages are loaded fairly level. However, if some peaked loading occurs, this further complicates system design. Half-round metal ducts, of 16- to 20-gage corrugated or smooth sheet metal with perforations uniformly spaced over the surface, are available commercially and are commonly used.

Ducts may be installed along the length or width of the storage, but crosswise ducts are preferred because they provide a better airflow distribution with shorter ducts, aeration can be started before the storage is filled, airflow can be concentrated in selected areas for removal of hot spots, and aeration can be continued after unloading has started in areas that still have stored cottonseed.

For level-loaded storages with crosswise ducts the duct size is calculated as given under "Duct Surface Area." The spacing of the ducts is determined by the depth of seed and the airflow rate used, but should not exceed 1½ times the depth of the seed. A spacing no greater than the seed depth is preferred. However, when the depth of cottonseed is more than 20 ft, duct spacing usually is reduced. For example, for an air velocity of 10 ft/min and cottonseed depths greater than 20 ft, the duct surface area required per foot length of duct exceeds 5 ft^2, requiring a half-round duct over 38 inches in diameter. Closer spacing permits use of smaller-diameter ducts; this usually is more economical and practical even though more ducts are needed.

In level-loaded storages with tight sidewalls, the aeration ducts may extend across nearly the entire width of the building (fig. 10). In storages requiring less duct surface area, the ends of the ducts may be several feet from the outside wall (fig. 11).

Storages having no central unloading tunnel can have crosswise aeration ducts connected to a supply pipe extending down the center of the storage on top of the floor. This supply pipe should be large enough to permit access to the gate valves for each cross duct. Supply pipes may also be provided under the floor (fig. 12). A more practical method with easier access to the gate valves is to locate a manifold pipe along the outside of the building, usually at floor level.

Wide storages with long ducts may have a manifold pipe on each side of the building (fig. 13). With this configuration, each half of the storage is essentially an independent aeration system. If the inner ends of two crosswise ducts are in contact, a block should be placed between them. In this way, each half of the ducting can be controlled independently.

For peak-loaded flat storages, greater consideration must be given to the size and spacing of the ducts because of the uneven depth of cottonseed. If the maximum depth of cottonseed is only half or slightly greater than the width of the storage, a central aeration duct placed lengthwise (fig. 14) may be sufficient. Such a system is practical in relatively small storages that can be filled rapidly and aeration started soon after filling. The system will also work well in larger storages, but the selection of areas through which to concentrate the air movement for removing hot spots is limited. An engineering analysis is important in a proposed duct system of this type.

One method of determining duct spacing is that used in designing grain aeration systems, as described in U.S. Department of Agriculture Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages." The ducts required are located lengthwise and spaced so that the longest air path served by any duct is no more than 1½ times the shortest air path served by that duct (fig. 15).

Another method, used with only two lengthwise ducts, is to locate each of them so that its horizontal distance from the outside wall is equal to the shortest distance (perpendicular distance) from the cottonseed surface to the duct (fig. 16). This can be done by scribing an arc,

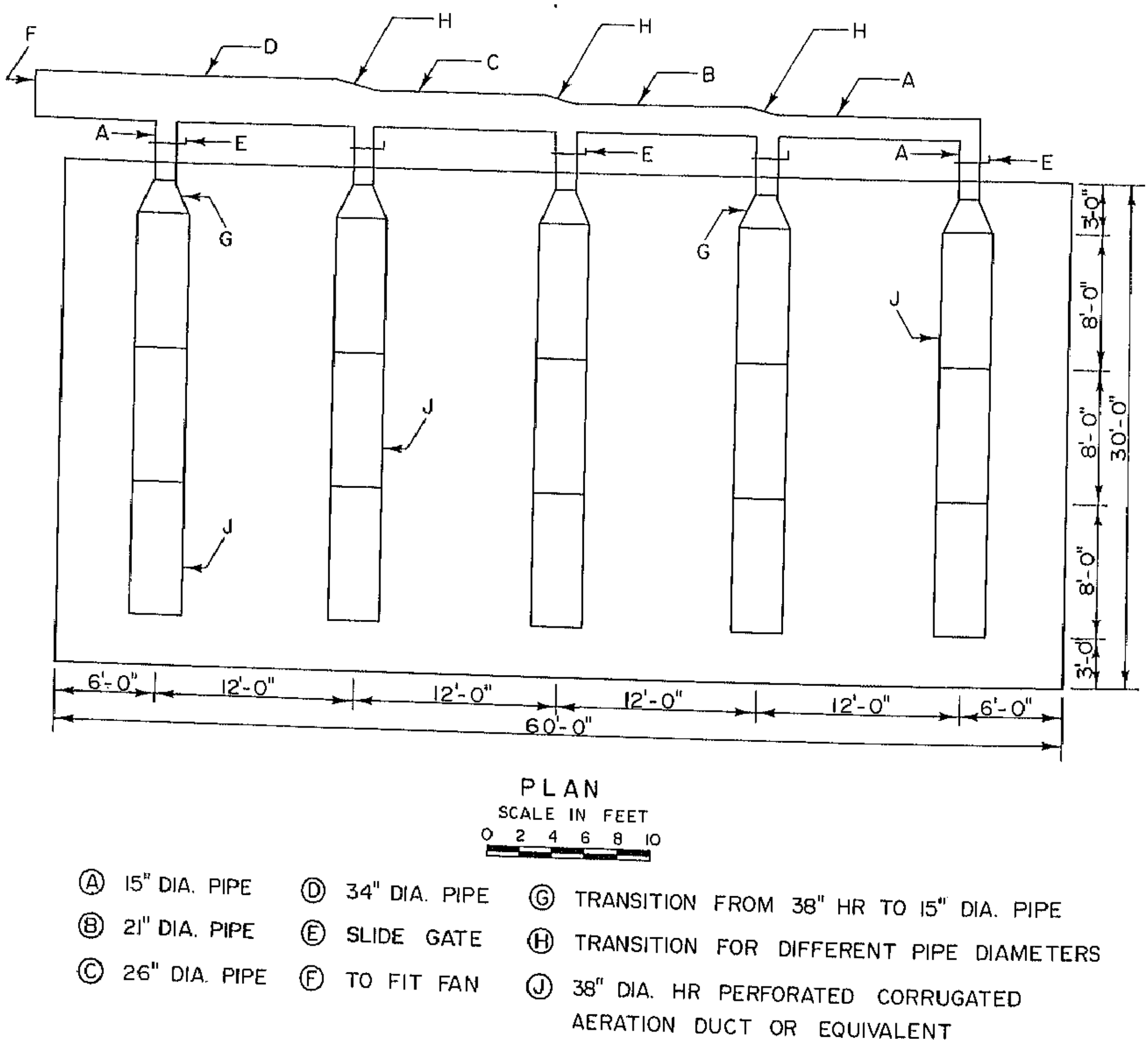

FIGURE 10—Aeration system layout for flat storage based on cottonseed 20 ft deep and aerated at 20 ft^3/min/ton.

with the duct location as the center point, to determine when the two distances are equal.

Tests in aerated commercial storages showed that air first moves radially in a half-circle area round the duct, then at right angles to the cottonseed surface depending on the spacing of the ducts and the depth of cottonseed. In grain studies, Ives, Hukill, and Saul[1] state: "In nonlinear or duct type (two-dimensional airflow) systems all airflow streamlines are straight and parallel above a level equal to approximately one-half of the center-to-center duct spacing, but there is a stagnation point, midway between the ducts, where there is practically no air movement." Because of this radial airflow, the cottonseed halfway between the ducts cools the slowest. Consideration must be given to duct spacing in order to minimize the amount of poorly aerated cottonseed between the ducts. As duct spacing is increased, the amount of cottonseed that cools too slowly also increases.

In peak-loaded storages where the cottonseed unloading tunnel is used as the supply pipe, the

[1] Ives, Norton C., Hukill, W. V., and Saul, R. A. 1959. Grain ventilation and drying patterns. Trans. ASAE (Am. Soc. Agric. Eng.) 12: 95–101.

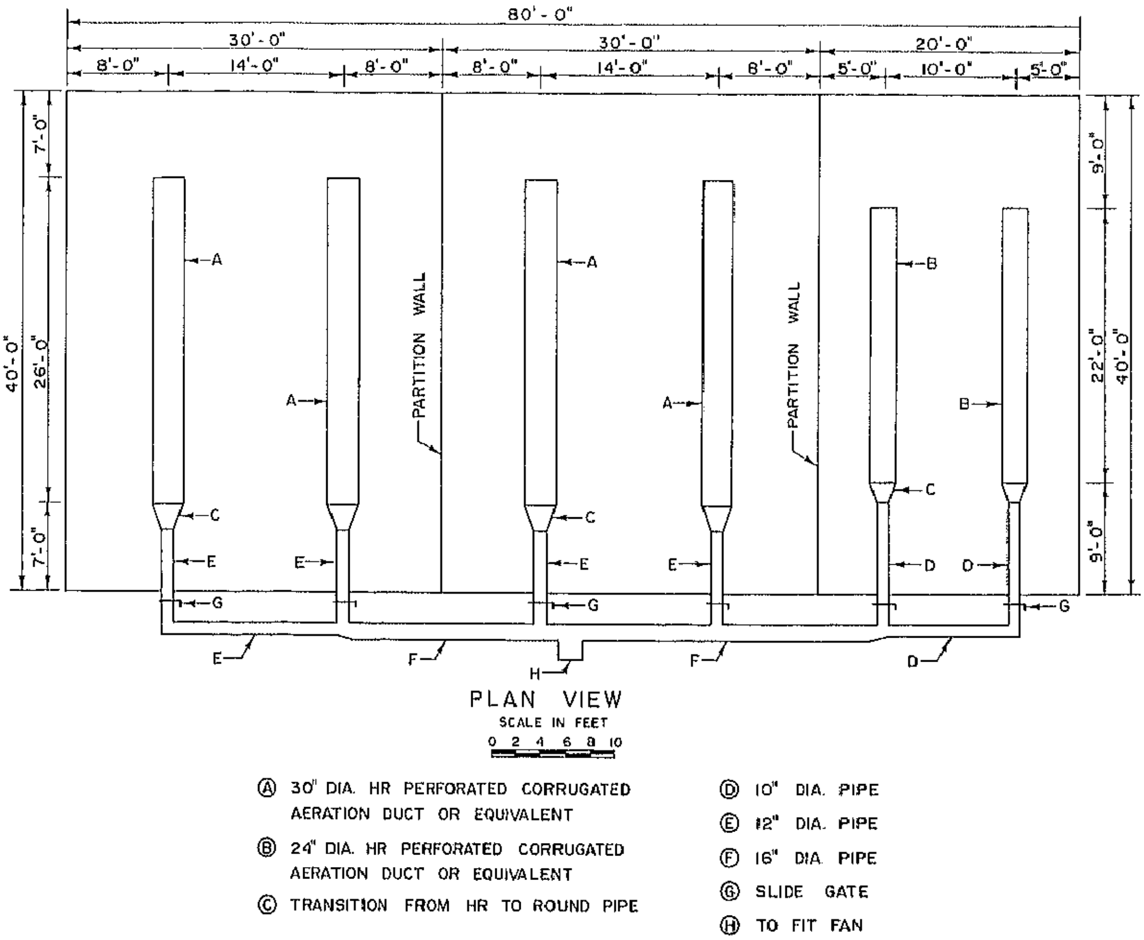

FIGURE 11.—Aeration system layout for flat storage based on cottonseed 14 ft deep and aerated at 10 ft^3/min/ton.

ducts may be larger in diameter but shorter in length to eliminate or reduce short air paths (fig. 17). The uneven depths make it necessary to reduce short circuiting of the air through the shallower parts of the cottonseed. One method of determining the duct length is to scribe an arc from the outer end of the duct, making the horizontal distance to the outside wall equal to the shortest distance (perpendicular distance) from the cottonseed surface to the duct. Analysis is necessary to determine duct sizes. Several duct sizes and lengths may be calculated and plotted to determine the best arrangement for a specific system.

Should a supply pipe be located under the floor of the cottonseed unloading tunnel (fig. 18) with the same system arrangement as given above, precautions must be taken to prevent short circuiting of the air from the tunnel into the ducts. Covering the tunnel with plastic sheeting so it extends out onto the floor is one way to seal the tunnel.

Ducts for Deep or Muskogee-Type Storages

In deep or Muskogee-type storages, designing an effective aeration system is more complicated than for the peak-loaded storage. Many systems now in use designed without sufficient consideration of the extreme variations in cottonseed depth. Thus, most of the cottonseed receives too little air to reduce sufficiently the gin heat or the heat of respiration. Hot spots can and do develop in the areas of greatest cottonseed depth.

Normally, pallets or other ducts, placed over small openings in the floor, lead to small supply pipes under the floor connecting the ducts to

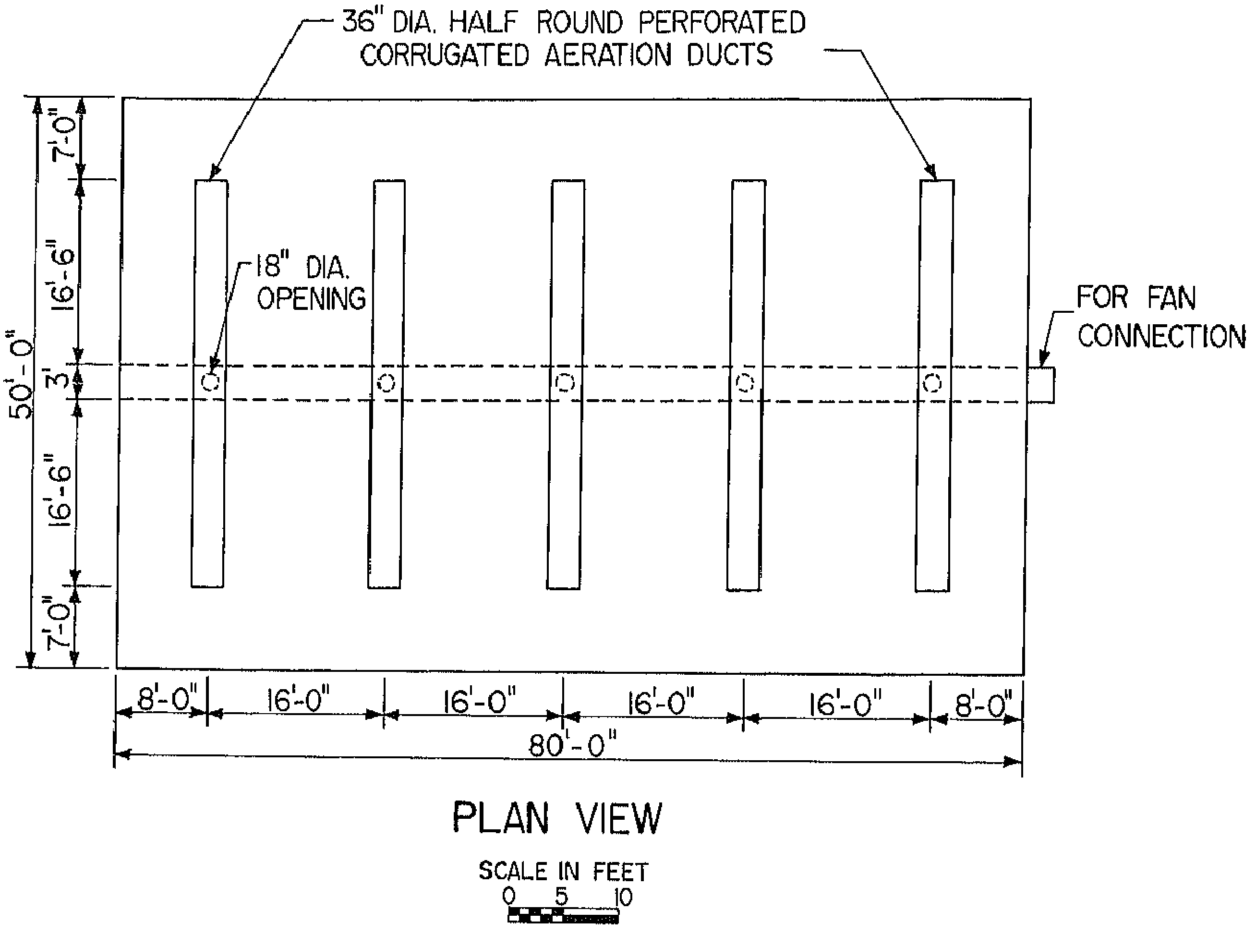

FIGURE 12.—Aeration system layout for flat storage based on cottonseed 20 ft deep and aerated at 8 ft^3/min/ton.

larger supply pipes leading to the fan. It is not uncommon for both of these supply pipes to be too small to carry enough air to do the job without large pressure losses and high power requirements. Usually the pallets are located too near the outside walls, in the shallower depths of cottonseed. They also may extend too near the unloading tunnel, with free air access to the tunnel. If this or a similar duct arrangement is used, air is short circuited through the lesser depths of cottonseed (fig. 19).

This kind of system may be improved by locating the ducts closer to the tunnel, where there is a greater depth of cottonseed. To prevent short circuiting of the air from the tunnel, it is neces-
...r to seal both ends to
...utside (fig. 20). In
...e covered with a considerable depth of cottonseed at all times in order to maintain effective cooling.

A better system for this type of storage is one that uses the unloading tunnel as the aeration duct. It is necessary to increase the effective open surface area of the tunnel sidewalls to reduce air velocity and pressure loss through the cottonseed in this area. One way to do this is to cover the tunnel with hardware cloth (fig. 21). Then, in effect, the whole tunnel becomes a large aeration duct.

Another method is to install a second covering over the tunnel. Wood pallets made of 2 by 4's and 2 by 6's are placed against the tunnel walls to increase the effective open surface area (fig. 22).

Part of each end of the unloading tunnel must be sealed against air movement to prevent too

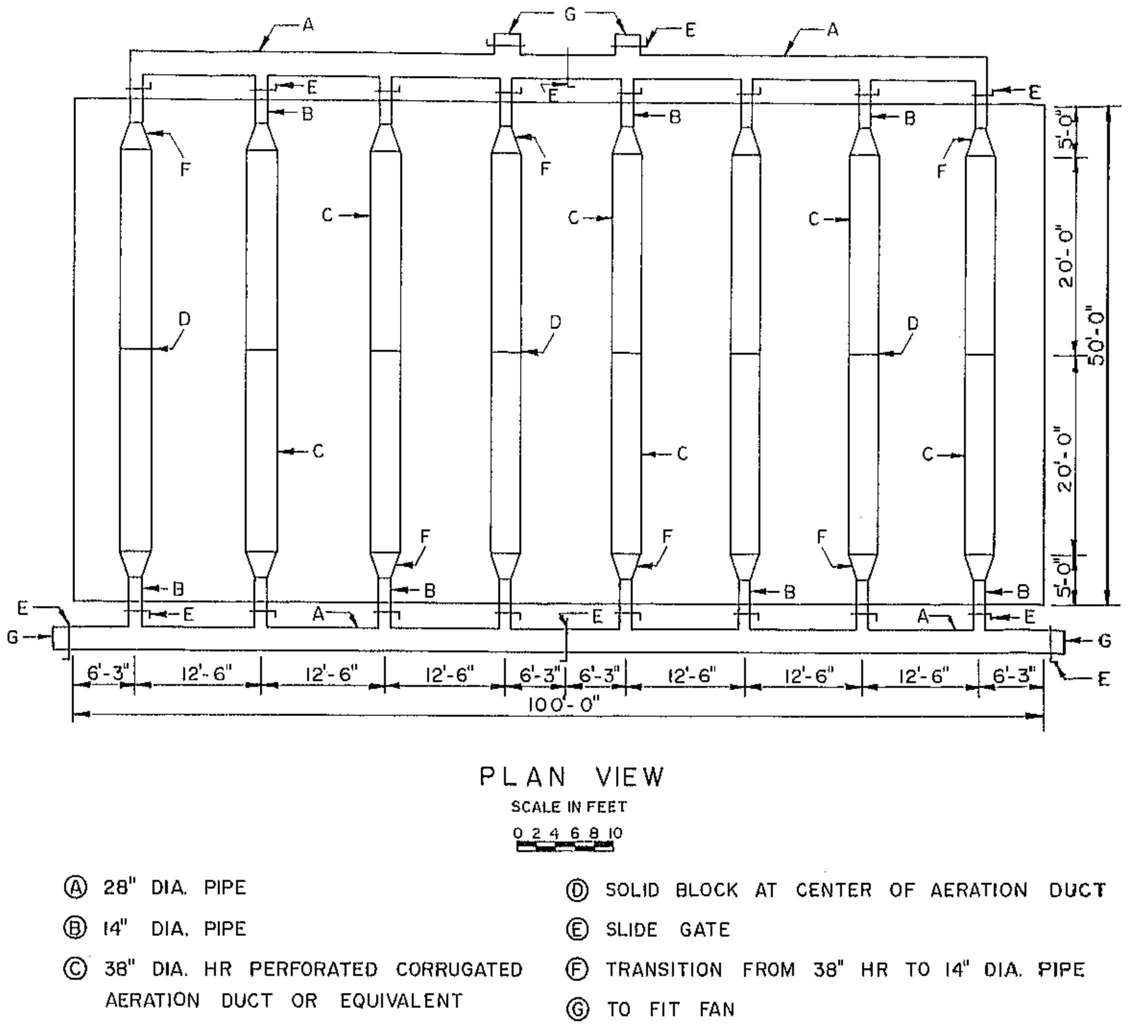

FIGURE 13.—Aeration system layout for flat storage based on cottonseed 20 ft deep and aerated at 20 ft^3/min/ton.

much air from moving through the shallower seed over the tunnel (fig. 23). The minimum length of tunnel to be covered in storages having a long roof slope is 45 to 50 percent of the horizontal projection of the roof (fig. 24). If adequate aeration surface area can be provided, it would be better to cover even more of the tunnel.

Usually the lower 2 ft of the tunnel sidewall are left uncovered, since, during unloading, cottonseed is moved through this space to the conveyor in the tunnel. This area at each end of the tunnel is sealed against all air movement by covering with plywood or some other supporting material. Plastic sheeting can be taped to the side of the tunnel above the open area and allowed to hang down over the plywood or other material and onto the floor a few inches. The cottonseed will hold the sheeting in place and seal against any airflow (fig. 23).

An analysis of the duct surface areas and cross sections and supply pipe sizes is important to the proper system design in these large storages. The air velocities through the duct surfaces and in the supply pipes should comply with the recommendations given above.

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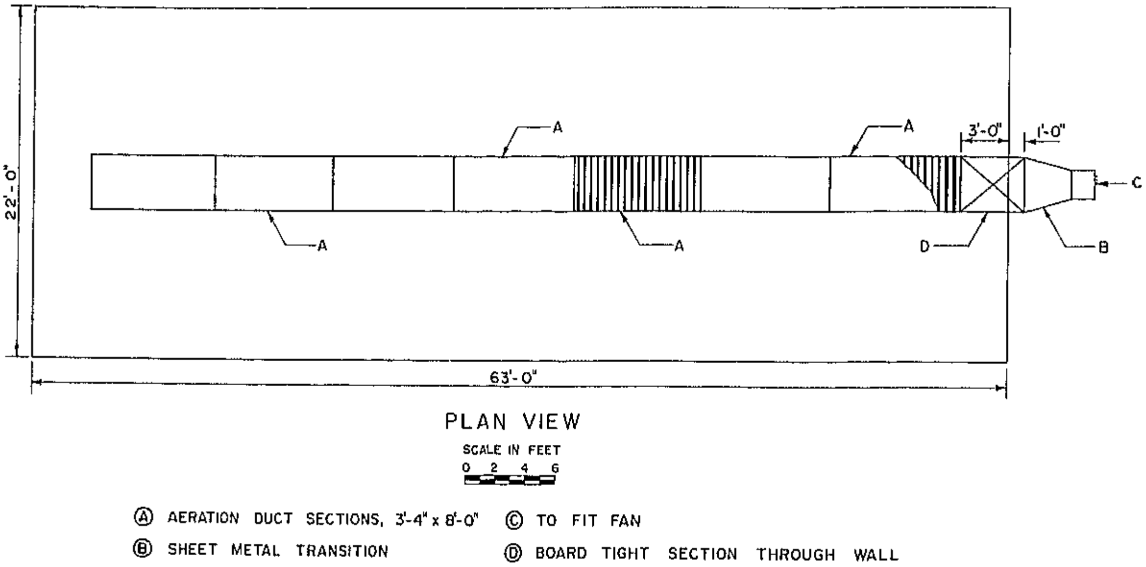

FIGURE 14.—Aeration system layout for flat storage when cottonseed is piled 4 ft higher along centerline than at sides and aerated at 10 ft³/min/ton.

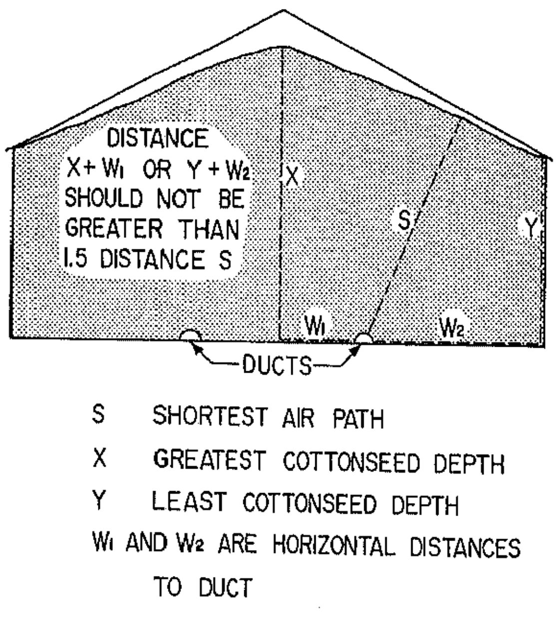

FIGURE 15.—Peak-loaded storage with lengthwise ducts spaced with longest air path not more than 1½ times the shortest path.

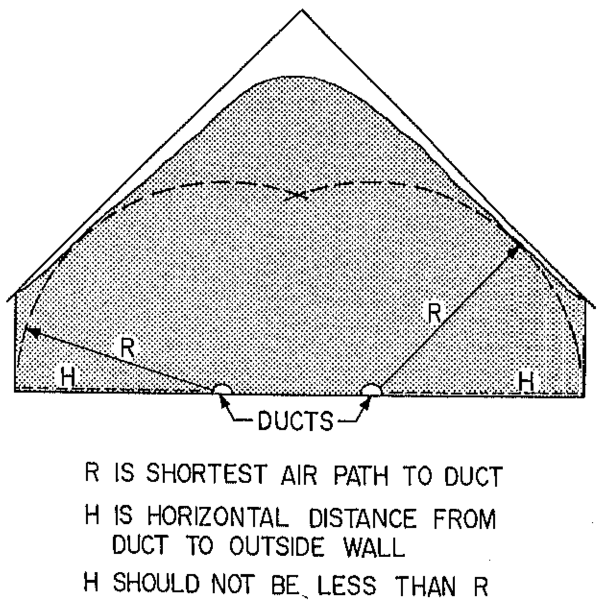

FIGURE 16.—Peak-loaded storage with two lengthwise ducts spaced with the horizontal distance not less than the shortest air path.

Supply Pipes

Supply pipes connect the duct with the fan and provide for air passage between the two. They are usually round, smooth, sheet-metal pipes. If embedded in the floor, they may be either tile or cast-iron pipe. Exposed sheet-metal pipes should be well supported and anchored. An air velocity of 2,500 ft/min is the maximum permissible for supply pipes; 1,500 ft/min is preferred.

Elbows are necessary to make turns in supply

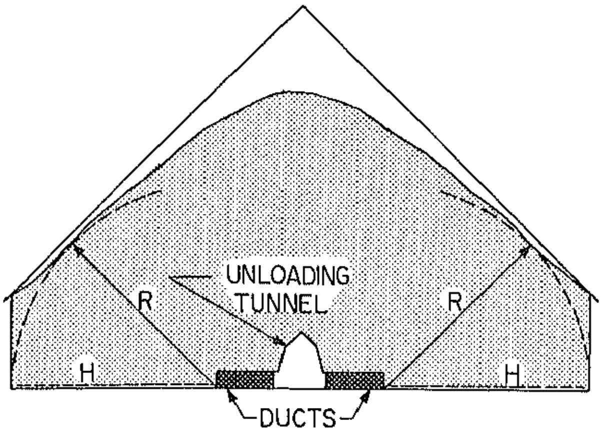

FIGURE 17.—Peak-loaded storage with unloading tunnel used as supply pipe and with short lateral ducts. The horizontal distance should not be less than the shortest air path.

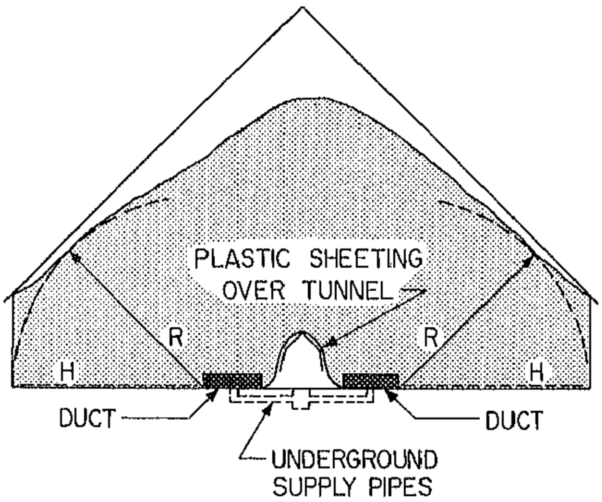

FIGURE 18.—Peak-loaded storage with supply pipes under the floor connected to short lateral ducts. Tunnel sidewalls are sealed to prevent the short circuiting of air into the ducts.

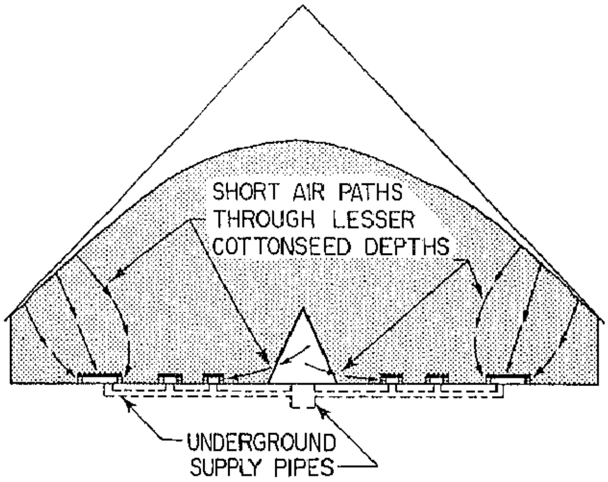

FIGURE 19.—Peak-loaded storage with pallets located too near the tunnel and too near the outside walls in shallow cottonseed. Air short circuits from the tunnel and through the shallow seed.

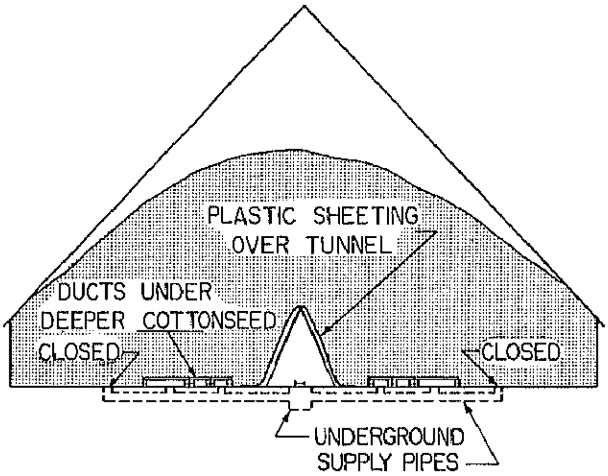

FIGURE 20.—Improved system with pallets located near the tunnel under deeper cottonseed. Tunnel sidewalls sealed against air movement into the ducts.

pipes. These range in shape from the simple miter (square) elbow to the multiple-piece elbow (fig. 25). Square elbows should be avoided wherever possible since they cause relatively high pressure losses due to friction. If the use of square elbows cannot be avoided, the pressure losses can be reduced from 10 to 30 percent of the velocity pressure by using splitters or vanes (fig. 26). However, the additional cost for these splitters may not be warranted to gain the savings in

power. There is probably little gain in using multiple-piece elbows with more than five pieces for small pipes and more than seven pieces for large pipes. Elbows with a centerline radius equal to at least 1½ times the pipe diameter are desirable with respect to both installation and operation.

Loss of air pressure in an elbow is usually expressed in terms of the length of straight pipe of the same diameter as the elbow that would give an equivalent loss. In illustration, assume two elbows of the same diameter carrying the same amount of air. The losses in a square elbow would be 4 to 5 times those in an elbow having a centerline radius of 1½ times the pipe diameter. Should a design call for an elbow at the end of the supply pipe, pressure losses can be reduced further by extending the pipe from the elbow a distance of 3 or 4 times the pipe diameter.

Branch connections in supply pipes should be designed to cut or slice into the airstream in order to reduce the pressure losses in them to a

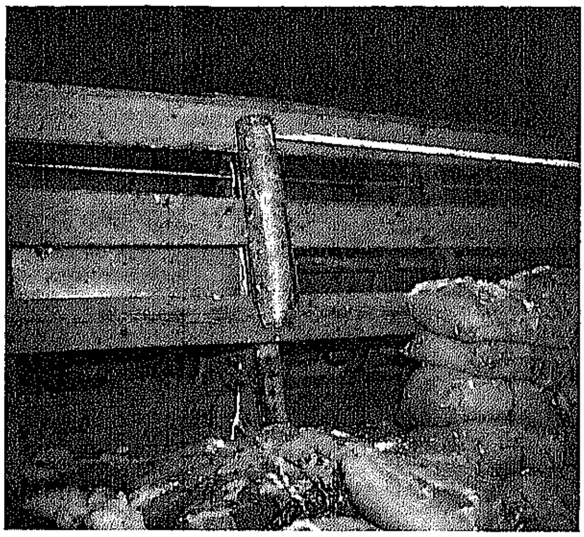

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FIGURE 21.—Tunnel sidewalls are covered with hardware cloth.

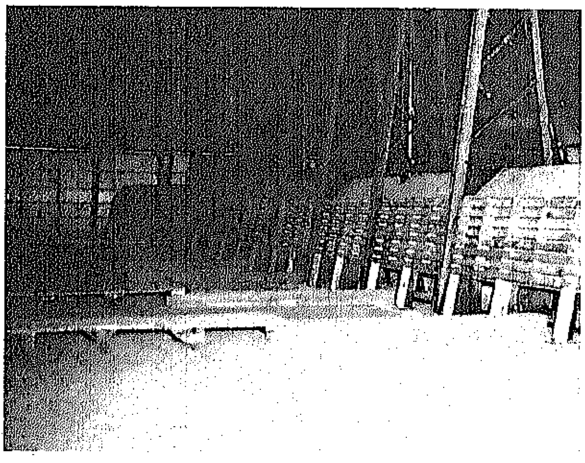

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FIGURE 22.—Pallets of 2-by-6 and 2-by-4 wood members are used to increase effective duct surface area.

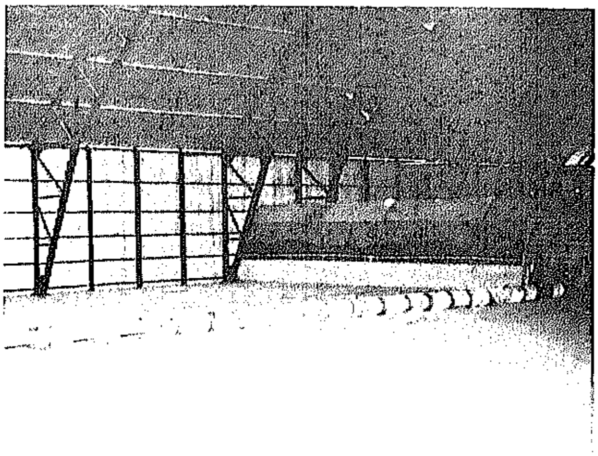

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FIGURE 23.—Portions of unloading tunnel sidewalls are sealed with plastic sheeting to prevent air movement through shallow depth cottonseed.

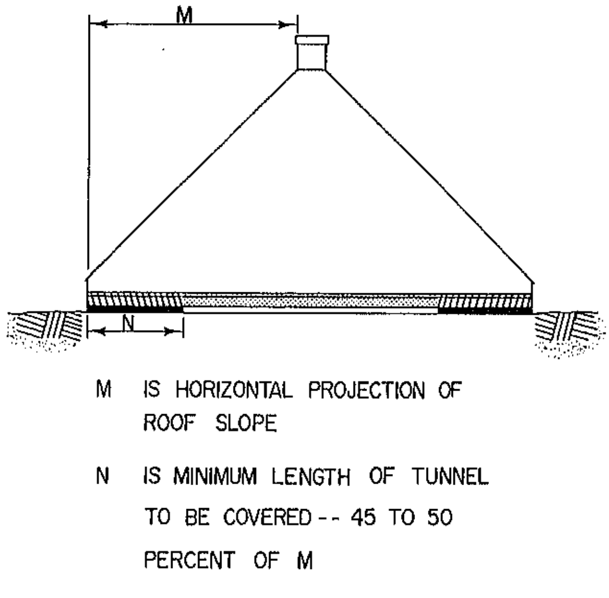
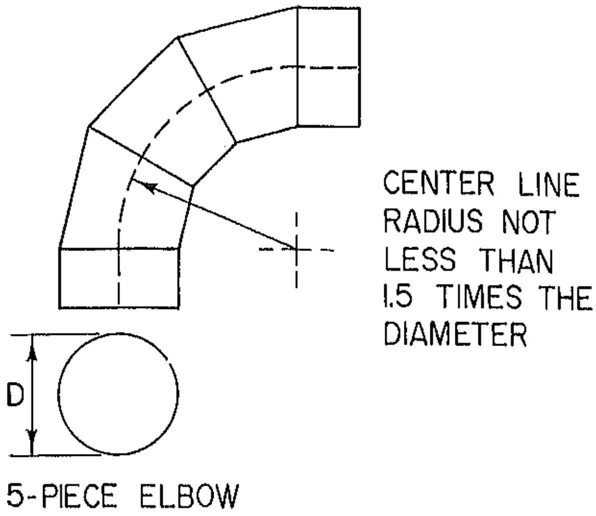


FIGURE 24.—A minimum length (N) of tunnel wall in a Muskogee-type storage should be sealed to prevent air entering the duct.



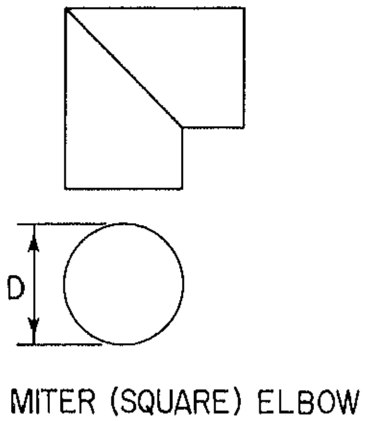


FIGURE 25.—Five-piece elbow (top) offers less resistance to airflow than miter elbow (bottom).

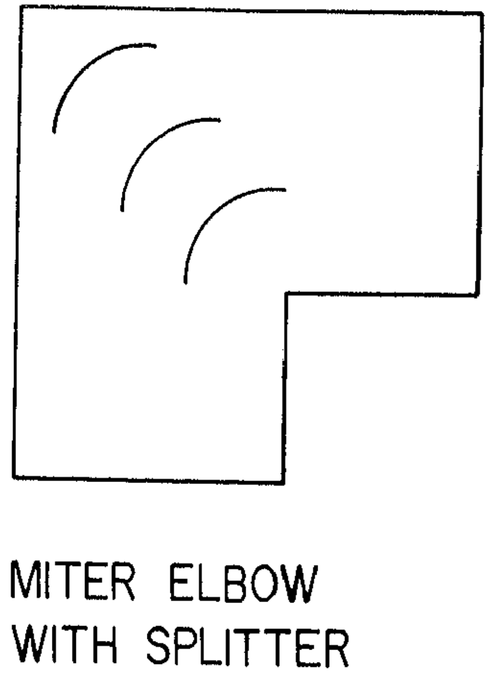


FIGURE 26.—Splitter section in miter elbow reduces pressure loss.

minimum. Abrupt changes in pipe size also cause air-delivery losses and should be avoided whenever possible.

With a manifold system, a slide gate or damper should be provided in the pipe from each duct to control the airflow from each duct.

A central duct system requires the least supply pipe. Usually only a short section is needed to connect the duct to the fan at either or both ends of the storage.

A slide gate in the short supply pipe can serve two purposes. It can be used as a damper (or throttle) to keep from overloading the motor if the storage is only partially filled, and it can be closed during periods of no fan operation. This will prevent air at a higher temperature than that of the cottonseed or high relative humidity from moving through it by convection.

Estimating Static Pressures Created and Fan Horsepower Requirements

Figures 27 and 28 provide information for estimating the static pressures created and the fan horsepower required when aerating cottonseed at different rates of airflow (ft^3/min/ton) and at depths of 10 to 80 ft. Static pressures were calculated from field observations and laboratory studies. Horsepower requirements and airflow rates were calculated using a cottonseed volume of 75 ft^3/ton.

Basic static pressures were increased to allow for pressure losses inside the ducts and the supply pipes. In depths of cottonseed of 45 ft and greater, the basic static pressures were increased an additional 10 percent for allowances for packed fill.

The cottonseed moisture content and the amount of linters on the seed may affect the total static pressures created and the horsepower requirements. Figures 27 and 28 provide only estimates of static pressure and fan horsepower. If cottonseed has excessive linters or is stored for

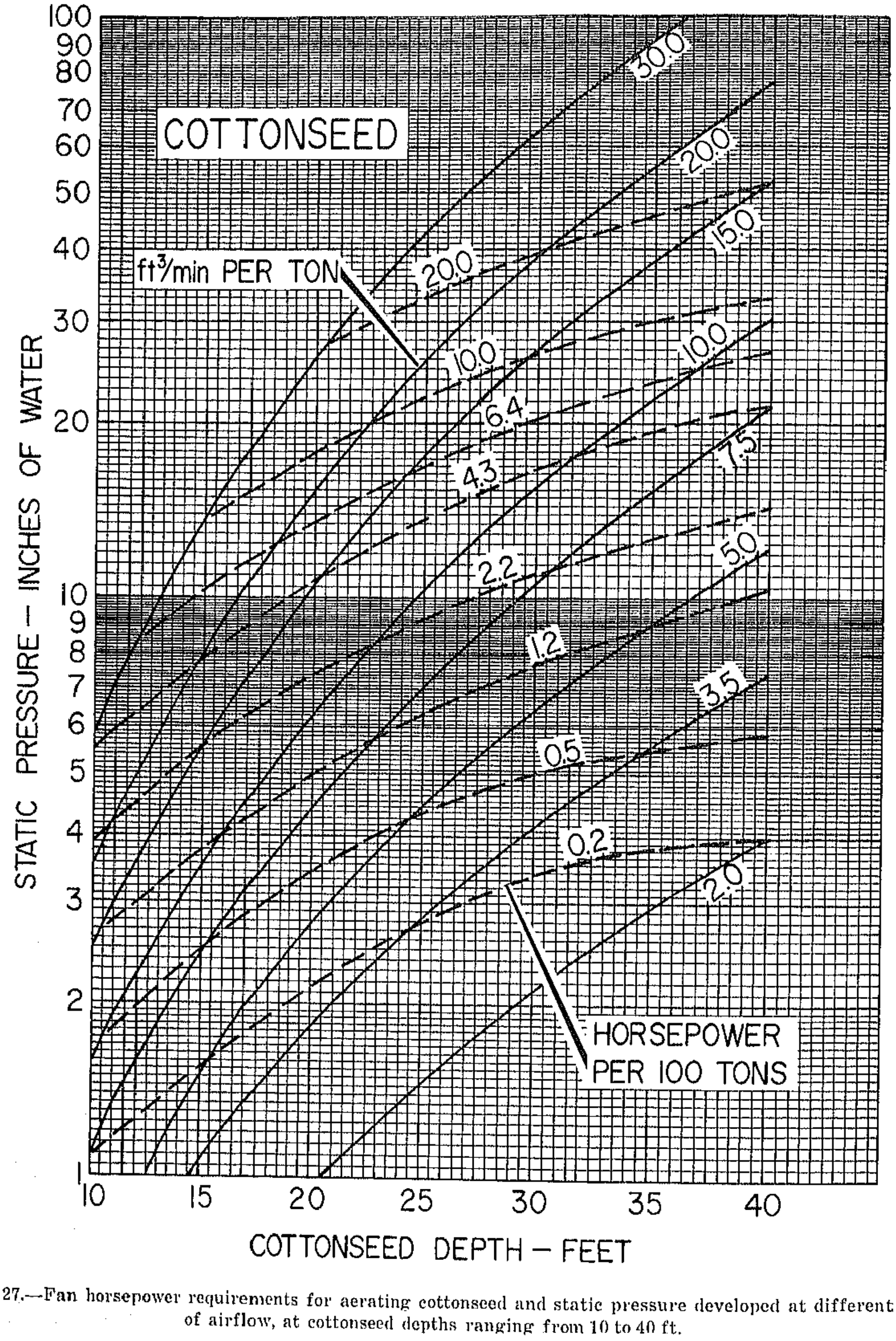


FIGURE 27.—Fan horsepower requirements for aerating cottonseed and static pressure developed at different rates of airflow, at cottonseed depths ranging from 10 to 40 ft.

long periods of time, the estimates may be low for both static pressure and fan horsepower.

The fan horsepower requirement is calculated as follows:

$$\text{Fan horsepower} = \frac{\text{ft}^3/\text{min} \times \text{total static pressure, in}H_2O}{6{,}356 \times \text{mechanical efficiency}}$$

A mechanical efficiency of 60 percent was assumed in calculating the fan horsepower required. Suppliers may furnish fans having different efficiencies; if this is the case, the horsepower requirements given in figures 27 and 28 should be adjusted accordingly. For example, assume that an aeration system requires 0.5 hp/100 tons of cottonseed as determined from figure 27. If the fan has a mechanical efficiency of 52 percent, the system would require the following horsepower:

$$\frac{0.5\ \text{hp}/100\ \text{tons} \times 0.60\ \text{(mechanical efficiency)}}{0.52\ \text{(mechanical efficiency of selected fan)}} = 0.58\ \text{hp}/100\ \text{tons}.$$

In using the charts for selecting a fan and motor, first consider these factors:

1. The size and type of structure in which the system is to be installed.
2. The maximum depth of cottonseed through which the air will be moved (in peak-loaded stor-

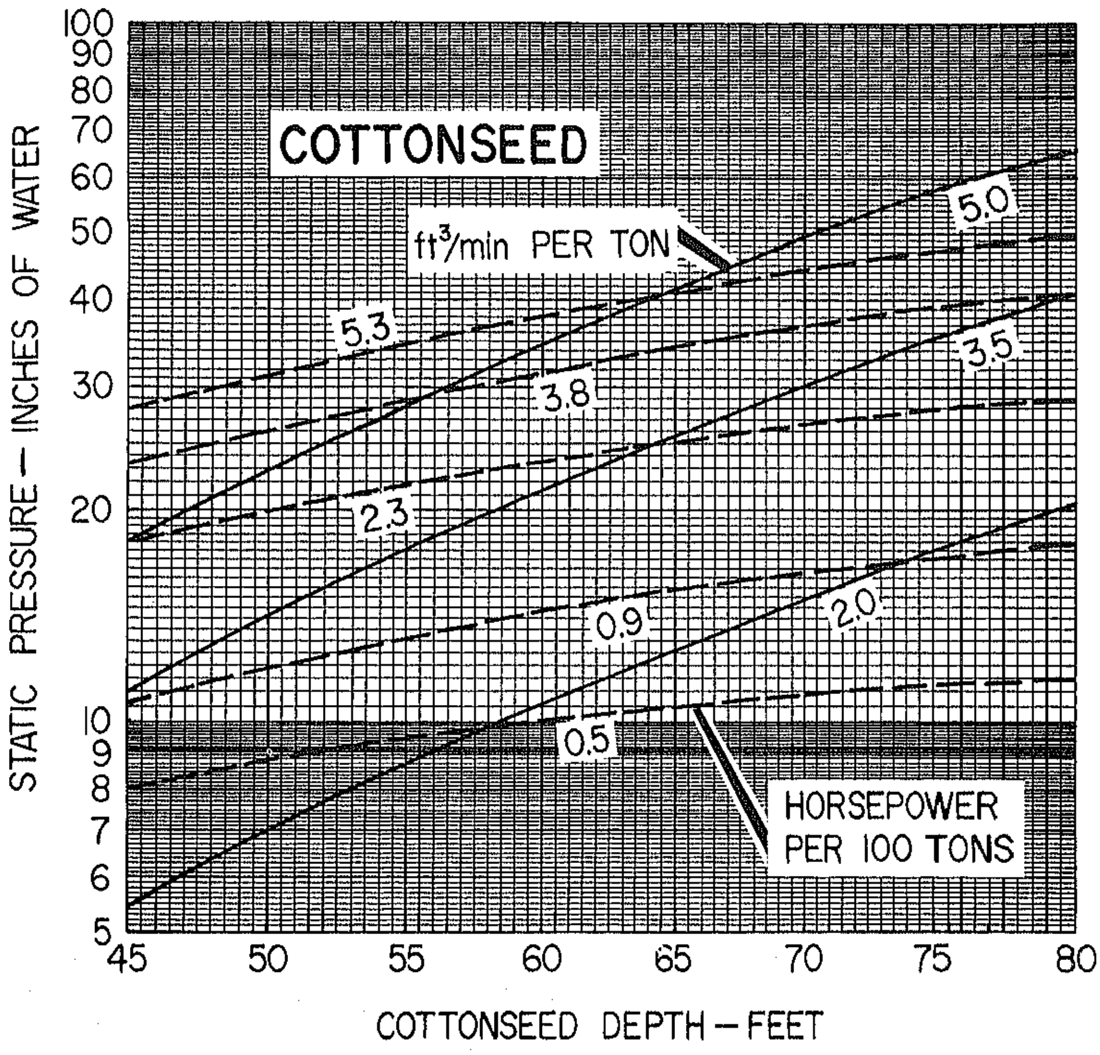


FIGURE 28.—Fan horsepower requirements for aerating cottonseed and static pressure developed at different rates of airflow, at cottonseed depths ranging from 45 to 80 ft.

ages the depth selected for design purposes may be somewhat less than the greatest depth at the peak).

3. The airflow rate to be provided per cubic foot or per ton.

4. The quantity of cottonseed to be served by each fan.

5. Total volume of air needed (total volume of cottonseed times airflow rate in cubic feet per minute per unit volume).

The use of the charts to determine fan horsepower and motor requirements is illustrated by the following examples:

A. An aeration system is designed for a flat storage with cottonseed to a depth of 16 ft (capacity 512 tons), using one fan; the cottonseed is to be aerated at 10 ft^3/min/ton (use fig. 27).

1. Find 16 ft at bottom of the chart.
2. Follow vertical line to the 10-ft^3/min/ton curve.
3. From ft^3/min curve follow horizontal line to left column of chart and read static pressure, 3.9 inH_2O (approximate).
4. Total air volume=512 tons×10 ft^3/min/ton=5,120 ft^3/min.
5. Repeat 1 and 2 above; then estimate where this point falls between the dash lines that indicate horsepower per 100 tons; in this case the point is on the dash line representing 1.2 hp/100 tons.
6. Total horsepower required is

$$\frac{512 \text{ tons}}{100} \times 1.2 \text{ hp/100 tons} = 6.14 \text{ hp.}$$

Note: A 7.5-hp motor would be selected unless the fan manufacturer can supply a more efficient fan requiring less horsepower. If a less efficient fan is used, more horsepower would be required, in accordance with the fan mechanical efficiency. Horsepower is calculated as previously shown.

B. An aeration system is designed for a peak-loaded storage with a maximum depth of 30 ft (capacity 2,690 tons), using two fans. For this peak-loaded storage use a depth of 25 ft; cottonseed is to be aerated at 10 ft^3/min/ton (use fig. 27).

1. Find 25 ft at the bottom of the chart.
2. Follow vertical line to 10-ft^3/min/ton curve.
3. From ft^3/min curve follow horizontal line to left column of chart and read static pressure, 10.5 inH_2O (approximate).
4. Total air volume=2,690 tons×10 ft^3/min/ton=26,900 ft^3/min.
5. Repeat 1 and 2 above; then estimate where this point falls between the dash lines indicating horsepower per 100 tons; in this case approximately 3.0 hp/100 tons.
6. Total horsepower required is

$$\frac{2{,}690 \text{ tons}}{100} \times 3 \text{ hp/100 tons} = 80.7 \text{ hp.}$$

Note: For two fans either two 40-hp or two 50-hp motors would be selected, depending on the efficiency of the fans. Horsepower is calculated as previously shown.

C. Same storage as above, but cottonseed to be aerated at 7.5 ft^3/min/ton (use fig. 27).

1. Find 25 ft at bottom of the chart.
2. Follow vertical line to 7.5-ft^3/min/ton curve.
3. From ft^3/min curve, follow horizontal line to left column of chart and read static pressure, 7.2 inH_2O (approximate).
4. Total air volume=2,690 tons×7.5 ft^3/min/ton=20,175 ft^3/min.
5. Repeat 1 and 2 above; then estimate where this point falls between dash lines indicating horsepower per 100 tons; in this case approximately 1.5 hp/100 tons.
6. Total horsepower required is

$$\frac{2{,}690 \text{ tons}}{100} \times 1.5 \text{ hp/100 tons} = 40.35 \text{ hp.}$$

Note: For two fans, two 20-hp or 25-hp motors would be selected, depending on the efficiency of the fans. Horsepower is calculated as previously shown.

D. An aeration system is designed for a peak-loaded and deep storage with a maximum depth of 95 to 100 ft (capacity approximately 18,000 tons), using two fans. For this peak-loaded deep

storage use a depth of 80 ft on the chart; cottonseed is to be aerated at 2 ft^3/min/ton (use fig. 28).

1. Find 80 ft at the bottom of the chart.
2. Follow vertical line to 2-ft^3/min/ton curve.
3. From ft^3/min curve follow horizontal line to left column of chart and read static pressure, 20 inH_2O (approximate).
4. Total air volume=18,000 tons×2 ft^3/min/ton=36,000 ft^3/min.
5. Repeat 1 and 2 above, then estimate where this point falls between the dash lines indicating horsepower per 100 tons; in this case approximately 1.3 hp/100 tons.
6. Total horsepower required is

$$\frac{18{,}000 \text{ tons}}{100} \times 1.3 \text{ hp/100 tons} = 234 \text{ hp}.$$

Note: For two fans, two 125-hp motors would be selected, unless the fan efficiency varies from the 60 percent assumed. Horsepower is calculated as previously shown.

Electric Motors

Electric motors for driving aeration fans are available in many sizes and types. The starting torque is low to medium for most fans. Most installations are designed for constant-speed operation.

Motor selection will depend on the electric service available, insurance ratings, and power supplier regulations. Local codes and ordinances must be observed when installing motors. A totally enclosed, fan-cooled motor usually is required for aeration duty where complete weather protection is needed. It is advisable to select a motor at least one size larger than the fan requires. Motors may be connected to the fan shaft directly or by V-belt drive.

Three-phase electric current will be available for most cottonseed aeration installations, since they will be located near ginning operations. Squirrel-cage induction motors are recommended and are available in all sizes likely to be needed from one-eighth horsepower and upwards. Standard voltages are 115, 230, and 460. Full-voltage starting usually is used. However, some power suppliers may require low-voltage starting. A check with the supplier is necessary, especially for motor sizes above 30 hp.

Single-phase induction motors are suitable for aeration fans, but are more expensive than three-phase motors. Many power companies limit the size of motors on single phase service to 7.5 hp.

Motor Controls

Motor controls for aeration fans should be installed in accordance with the National Electric Code and the requirements of local codes and authorities. The control equipment should include (1) means of disconnecting the motor from the power supply, (2) means of starting and stopping the motor, and (3) overload and low-voltage protection for the motor.

A motor starting switch, either magnetic or manual, is necessary for motors of 1 hp and larger. These switches also should have built-in overload protection. Smaller motors should have built-in overload protection or have time-delay fuses or circuit breakers rated according to motor amperage. Fuses or automatic circuit breakers are necessary in motor circuits to protect against short circuits in the wiring.

Automatic motor controls are used to limit aeration to periods when atmospheric conditions are favorable, and to reduce the time required for the operator to start and stop the fan motors. At present, automatic controls are not generally used for operating cottonseed aeration fans. However, total operating time can be reduced greatly when automatic controls are used, because they prevent the reheating that takes place during continuous operation when air temperatures are higher than the cottonseed temperature. They make fan operation possible during the night, on weekends, and on holidays when there may not be anyone on duty. Automatic controls also permit the maximum use of the most favorable weather conditions. With manual controls, good aeration weather is often not used to advantage.

Standard heating and air-conditioning thermostats and humidistats are generally used in the makeup of automatic motor controls. Some automatic controls are available commerc
Other instruments such as clocks, pilot l

elapsed time meters, interval timers, and selector switches can be added to the system for more precise control.

A circuit diagram for a control system employing a high-limit thermostat, a low-limit thermostat, a humidistat (all three connected in series), and an elapsed time meter is shown in figure 29. The high-limit thermostat prevents fan operation when the air temperature is above the set point, and the low-limit thermostat prevents operation when the air temperature is below the set point. The humidstat prevents operation when the relative humidity is above the set point.

In oil-seed storages, the low-limit thermostat is not necessary where the lowest temperature obtainable is not objectionable. However, since planting seed is not generally cooled below 50° F, a low-limit thermostat is necessary where it is stored.

The control-panel enclosure should provide for free movement of the surrounding air and be located so that the controls and the fan inlets will be subjected to the same atmospheric conditions. A shady location protected from dust and wind is best.

Automatic controls should be inspected and serviced regularly to keep them in good working order. The sensing elements in humidistats are particularly sensitive to dust and air pollution, which can impair controller action. They must be kept clean as directed by the manufacturer. Under particularly dirty air conditions, these hairsensing elements may need to be replaced every year or two.

GENERAL OPERATING CONDITIONS FOR AERATION SYSTEMS

Although aeration is one method of maintaining the market quality of stored cottonseed by moving through it atmospheric air of acceptable temperature and relative humidity, the quality and moisture content of the cottonseed to be aerated are important. It is obvious that aeration cannot be expected to improve substantially cottonseed of low market quality.

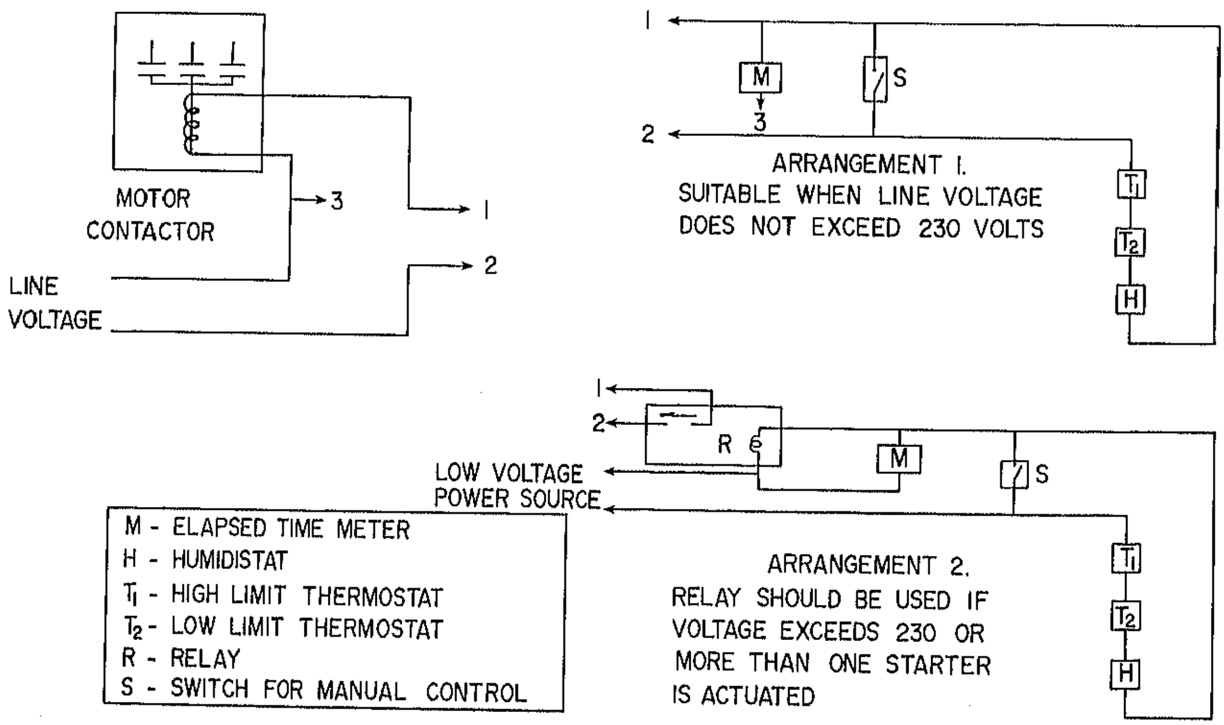


FIGURE 29.—Wiring diagram to connect controllers in series with fan motor contractor.

Cottonseed Moisture Content

Cottonseed is hygroscopic and therefore absorbs moisture from or gives up moisture to the surrounding air. When it does neither it is said to be at its equilibrium moisture content for the prevailing air temperature and relative humidity. Only limited information is available on equilibrium moisture content for cottonseed. However, the following tabulation gives some relative humidities and corresponding cottonseed equilibrium moisture contents at 79° F.

Equilibrium moisture content, percent	Relative humidity
8	49
9	59
10	69
11	75
12	78
13	80

Atmospheric Conditions

Air temperature and relative humidity change frequently during the day. Proper setting of the temperature and humidity controls permits aeration under the most favorable atmospheric conditions. If automatic controls are not used, a knowledge of atmospheric conditions before and during aeration will be of benefit.

Table 2 lists some maximum operating temperatures for cooling cottonseed in specific months and areas. These settings, selected on the basis of past weather records, are suitable for either manual or automatic fan control. A high-limit thermostat set at one of these temperatures will prevent the fans from running above these settings. However, good results have been obtained where manual control was used and fans were operated only when the air was at these or lower temperatures. When cottonseed is cooled to these temperatures or slightly below, the fans can be stopped until cooler air is available.

Continuous aeration of cottonseed with air at relative humidities higher than those given in table 2 can result in an increase in cottonseed moisture content. It is advisable to aerate cottonseed with air having average humidities approximating those in the tabulation. However, aeration for extended periods with air at a relative

TABLE 2.—*Suggested maximum monthly operating air temperatures for cooling cottonseed in the Mississippi Delta and Southeast*

Month	Degrees F[1]	
	Mississippi Delta	Southeast
August	...	85
September	85	85
October	70	70
November	55	60
December	50	45
January	[2]45	45
February	[2]45	50

[1] Allows approximately 6 hours of operation each day at relative humidities below 80 percent.

[2] For fan operation above 35° F for planting seed, expected daily operation for January is 2.5 hours, and for February, 4.5 hours.

humidity of 80 percent has been satisfactory where the air temperature is at least 10° F lower than the cottonseed temperature. Cottonseed aerated under these conditions should be checked frequently for any increase in moisture content. Normally, air humidities range from 100 percent at night and in the early morning to well below 60 percent on clear days. Fan operation is satisfactory when the average daily humidities do not exceed these limits. However, if cottonseed is at 95° to 100° F or higher and has some excess moisture when placed in storage, it may be advisable to run the fans even if the humidity is over 80 percent. Some cooling will be accomplished. The aeration airflow rates usually used are so low that any moisture increase in the cottonseed will be small. The fans may be stopped manually during periods of rain and fog. Also, a humidistat may be used to stop fan operation automatically during such high-humidity periods as rain or fog.

Satisfactory Cottonseed Temperatures

Field studies and experience indicate that temperatures below 60° F are beneficial to stored cottonseed. Temperatures of 35° to 45° F have proven satisfactory. The rate of removal of cot- tonseed from storage is usually slow enough t' there is no danger of moisture condensati curring even on seed with these low t tures. It is advisable that planting cotton

be cooled below 50° F to protect seed viability. Temperature equalization is important, and especially so in planting seed.

Cooling Zone

During aeration, a cooling zone is established and moves through the cottonseed in the direction of the airflow. All of the cottonseed behind the cooling zone will be at or near the entering air temperature. Ahead of the cooling zone, the cottonseed will be near its initial temperature. The depth and shape of the zone will depend on airflow rate and distribution. The lower the rate, the narrower the cooling zone. During the cooling process several zones may be moving through the seed at the same time.

Figure 30 represents cooling zones or equal-temperature lines that occurred in a peak-loaded storage with cottonseed depths to 80 ft, with an airflow rate of about 2 ft³/min/ton. The effects of peak loading with warm cottonseed from the top of the storage is evident in figure 30*A* after 520 hours of fan operation by November 21, 1968. Continued aeration until December 5, 1968, a total of 800 hours of fan operation resulted in the conditions shown in figure 30*B*. Figure 30, *C* and *D*, represents the location of cooling zones on December 20, 1968, and January 21, 1969, after 1,032 and 1,170 hours of fan operation, respectively.

As the cottonseed cools by stages, the airflow rate must be adequate to move a cooling zone through all the cottonseed in sufficient time to prevent deterioration. This is an important factor to consider in establishing time limits for completing a cooling stage. Reasonable power requirements and favorable weather conditions are factors to consider in selecting airflow rates.

Time Required for Cooling

The time required for cooling cottonseed or for the moving of a cooling zone through cottonseed is not well established. However, a general guide, obtained from field studies, indicates that an airflow rate of 5 ft³/min/ton will require about 110 hours to move a cooling zone through cottonseed during late fall with fan operation limited to temperatures below 55° F (table 2).

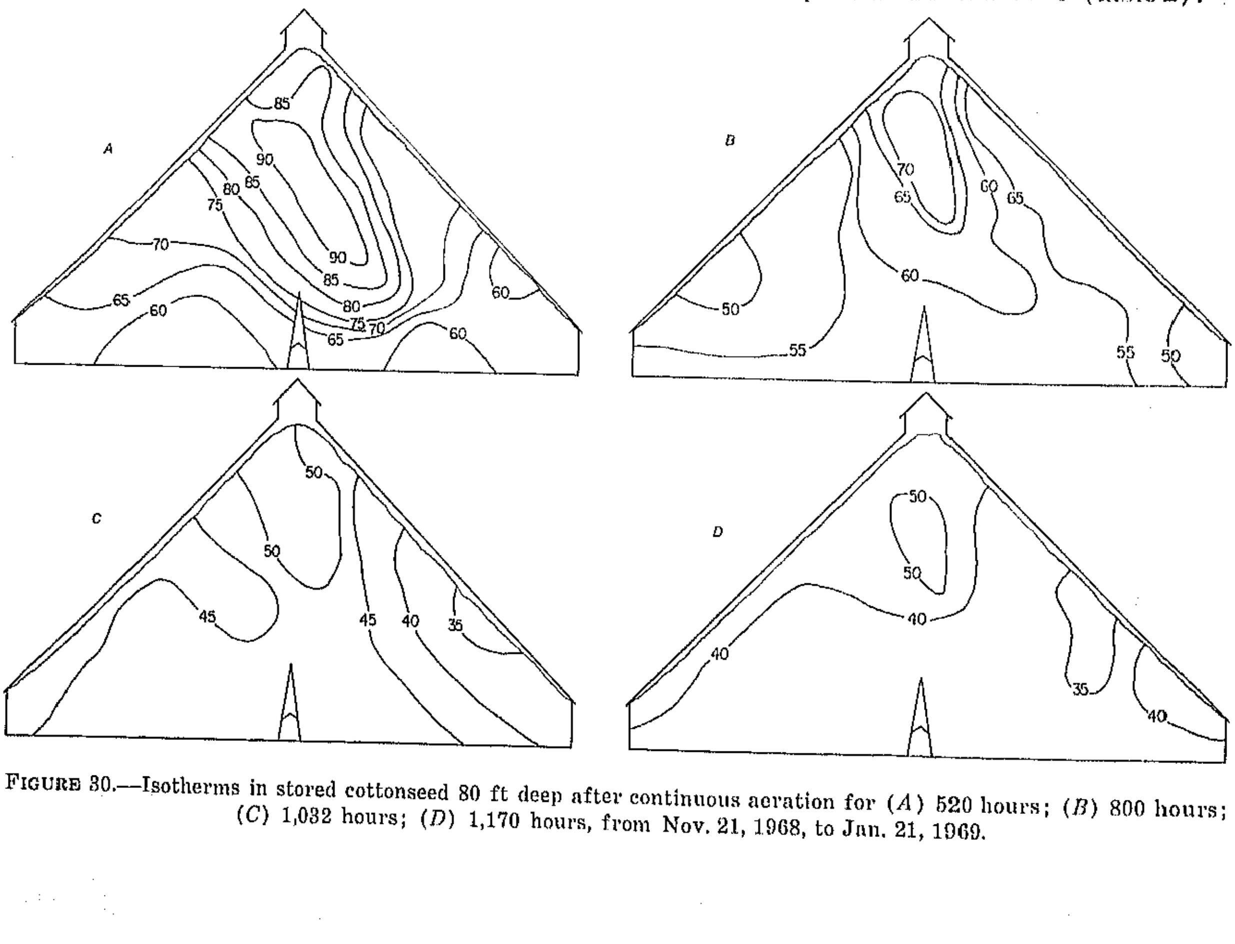


FIGURE 30.—Isotherms in stored cottonseed 80 ft deep after continuous aeration for (*A*) 520 hours; (*B*) 800 hours; (*C*) 1,032 hours; (*D*) 1,170 hours, from Nov. 21, 1968, to Jan. 21, 1969.

The time required for cooling with airflow rates other than 5 ft^3/min/ton is inversely proportional to the airflow rate used. That is, if the airflow rate is increased to 10 ft^3/min, the estimated hours of fan operation are approximately one-half those for 5 ft^3/min.

Aeration to remove ginning heat usually is started as soon as the first lots are in storage. As aeration and loading continue, many cooling zones are formed and move through the cottonseed at the same time. Although there are times when very little cooling occurs, experience has shown that seed quality can be maintained because aeration removes the heat and moisture of seed respiration. The total fan running time necessary may be greater than when operating the fans intermittently based on favorable weather conditions.

Use of Temperature-Detecting Devices

Many storage operators closely check temperature changes in their stored cottonseed. The rate of filling the storage, the time of harvest season, and weather conditions and seed moisture during harvest will determine the frequency with which temperature observations are made. The quality of the seed and the ease with which the temperature measuring equipment can be used may also influence the frequency of observations.

The most common temperature-indicating device is the mercury thermometer. Many storage operators use the thermometer for finding cottonseed temperatures by attaching it to the end of a pipe and probing it into the seed at selected locations and depths. After a given time, it is removed and read quickly. This method gives a fair indication of the cottonseed temperature, but considerable error is possible.

Another method of using the mercury thermometer is to tie several thermometers to a line or strong cord at selected intervals. The line and thermometers are then lowered into an upright pipe or conduit previously probed into the cottonseed. This method, with the thermometers always suspended at the same depth and location, provides a more accurate temperature indication than the first method described, if thermometers are read quickly. Both methods are limited in the depth at which temperatures can be obtained.

Other temperature-measuring devices are bimetallic and recording thermometers, thermistors, and electrical resistance elements, but they have limited application in cottonseed storages.

Thermocouples are widely used for indicating temperatures in devices ranging from modestly priced portable systems to most advanced remote automatic recording systems. A thermocouple consists of two insulated wires of dissimilar metal wound on a steel cable and encased in an abrasion-resistant covering. These cables may be suspended permanently from the bin roof and connected to a centrally located measuring instrument (potentiometer) where the temperature can be observed.

In shallow storages the cables may be suspended from the bin roof or crossmembers of the structure, or they may be probed into the cottonseed after the bin is filled. If they are left in place and observed regularly, they provide for a continuous record of storage temperature conditions.

For oilseed storages, a satisfactory spacing of the thermocouple cables is from 20 to 24 ft horizontally. Spacing of the thermocouples in the cables may range from 5 to 8 ft. To obtain more complete records in planting-seed storages, the cable spacing should be reduced and thermocouples within the cables may be at 3- or 4-ft intervals.

Detection of trouble spots between the thermocouple cables depends upon additional periodic inspections with thermocouple cables probed into suspected areas. High cottonseed temperatures warn of excessive moisture or exceptionally low aeration airflow. Temperatures must be taken regularly and the results recorded for future reference. When any abnormally high temperature is found, records should be made daily until the condition has been corrected. Temperatures should be recorded at least once a week during regular aeration until all the seed has reached the desired temperature. Once the seed has been cooled, the time between readings can be extended. However, temperature observations should be continued with some degree of regularity.

Cottonseed exerts considerable friction on thermocouple cables. Therefore, cables sus-pended from the roof may create a large f on the roof or other members of the stru Before suspending thermocouple cables fro

roof or crossmembers, it is advisable to check with the building designer regarding the strength of a structure.

Cost of Aeration Systems and Savings Possible Through Their Use

Cost figures for installation of a completely new aeration system in a new storage are not readily available. However, a fair estimate can be arrived at by obtaining cost figures for the following aeration system components:

1. Aeration duct and supply pipes.
2. Fan (s) and motor (s).
3. Electric wiring and motor starter (s).
4. Automatic controls.

A complete aeration system with manual controls was installed in a cottonseed storage built in 1968, with a capacity of 1,820 tons, at a cost of approximately $15,400, or approximately $8.45 per ton. The cost of this system, which was designed to aerate cottonseed 16 ft deep at a rate of 30 ft^3/min/ton, is somewhat higher than most recommended systems. If the system had been designed for a rate of 10 ft^3/min/ton, the cost probably would have been at least one-third less.

The cost of electricity for operating the system will depend on local rates for electric power and on hours of fan operation. If aeration is started soon after filling of the storage starts, many hours of fan operation can accumulate. Frequent observations of cottonseed temperatures and the selection of the most favorable weather conditions for aeration can result in appreciable power savings. During the 1966–67 storage season over 1,300 hours less fan operation was used than the previous year to cool a 14,000-ton cottonseed storage. Automatic controls were not used. However, discretion was used in the selection of good aeration weather conditions. Two 75-hp motors are used with this system. Based on power costs of 2¢ per kilowatt-hour, $2,000 can be saved in one season.

Additional savings are realized with improvements to existing systems. In one storage of 2,400 tons, a 75-hp motor was required to drive the aeration fan, which provided air to only 10 percent of the storage at a time. Improvements made to the system included installation of two fans, each powered by a 7.5-hp motor. The improved system was more effective and permitted the whole storage to be aerated at one time.

Improvements made to the aeration system in a storage 40 by 80 by 14 ft with a capacity of approximately 550 tons reduced the power requirements from a 40- to a 5-hp motor. The improved system (fig. 9) also provided for a 50-percent increase in total air volume over the old system. The improved system results in better air distribution, more rapid cooling, and less fan operating time required—all these conditions contribute to lower operating costs.

In the appendix, following, are tabulations of equipment, data, and examples showing how to design aeration systems for several storages of typical styles and capacities.

APPENDIX

Examples beginning on page 32 show how to design aeration systems for storages of different architecture and loading practices. Design information used in the examples is given in tables 3–6, following.

The examples are based on dimensions typical of the various styles and employ the data and methods presented in this publication.

TABLE 3.—*Surface area of half-round ducting*

Diameter, in	Surface area, ft²/lin ft	Diameter, in	Surface area, ft²/lin ft
15	1.963	34	4.451
19	2.487	36	4.712
20	2.618	38	4.974
22	2.880	40	5.236
24	3.142	42	5.500
25½	3.338	44	5.760
26	3.403	46	6.021
28	3.665	48	6.283
30	3.927	50	6.545
32	4.189	52	6.807

LE 4.—*Supply-pipe sizes and air-carrying capacities in cubic feet per minute at specified velocities*

ipe ieter, n	Section area, ft²	Air-carrying capacity at — 1,500 ft/min	2,000 ft/min	2,500 ft/min	Pipe diameter, in	Section area, ft²	Air-carrying capacity at — 1,500 ft/min	2,000 ft/min	2,500 ft/min
	0.136	204	272	340	23	2.885	4,328	5,770	7,213
	.196	294	392	490	24	3.142	4,713	6,284	7,855
	.267	401	534	668	25	3.409	5,114	6,818	8,523
	.349	524	698	873	26	3.687	5,513	7,374	9,217
	.442	663	884	1,105	27	3.976	5,964	7,952	9,940
	.545	818	1,090	1,363	28	4.276	6,414	8,552	10,690
	.660	990	1,320	1,650	29	4.587	6,881	9,174	11,468
	.785	1,178	1,570	1,963	30	4.909	7,364	9,818	12,273
	.922	1,383	1,844	2,305	31	5.241	7,862	10,482	13,103
	1.069	1,604	2,138	2,673	32	5.585	8,378	11,170	13,963
	1.227	1,841	2,454	3,068	33	5.940	8,910	11,880	14,850
	1.396	2,094	2,792	3,490	34	6.305	9,458	12,610	15,763
	1.576	2,364	3,152	3,940	35	6.681	10,022	13,362	16,703
	1.767	2,651	3,534	4,418	36	7.069	10,604	14,138	17,673
	1.969	2,954	3,938	4,923	37	7.467	11,201	14,934	18,668
	2.182	3,273	4,364	5,455	38	7.876	11,814	15,752	19,690
	2.405	3,608	4,810	6,013	39	8.296	12,444	16,592	20,740
	2.640	3,960	5,280	6,600	40	8.727	13,091	17,454	21,818

TABLE 5.—*Circumferences and cross-sectional areas of round pipes, by inches of diameter from 1 to 50*

Diameter, in	Circumference		Area		Diameter, in	Circumference		Area	
	in	ft	in²	ft²		in	ft	in²	ft²
1	3.14	0.262	0.78	0.005	26	81.7	6.81	530.9	[illegible]
2	6.28	.524	3.14	.022	27	84.8	7.07	572.6	[illegible]
3	9.42	.785	7.07	.049	28	88.0	7.33	615.7	[illegible]
4	12.57	1.047	12.57	.087	29	91.1	7.59	660.5	[illegible]
5	15.71	1.309	19.63	.136	30	94.2	7.85	706.9	[illegible]
6	18.85	1.571	28.27	.196	31	97.4	8.12	754.8	[illegible]
7	21.99	1.833	38.48	.267	32	100.5	8.38	804.2	[illegible]
8	25.13	2.094	50.27	.349	33	103.7	8.64	855.3	[illegible]
9	28.27	2.356	63.62	.442	34	106.9	8.90	907.9	[illegible]
10	31.42	2.618	78.54	.545	35	110.0	9.16	962.1	[illegible]
11	34.56	2.880	95.03	.660	36	113.1	9.42	1,017.9	7.07
12	37.70	3.142	113.10	.785	37	116.2	9.69	1,075.2	7.47
13	40.84	3.403	132.73	.922	38	119.4	9.95	1,134.1	[illegible]
14	43.98	3.665	153.94	1.069	39	122.5	10.21	1,194.6	8.30
15	47.12	3.927	176.71	1.227	40	125.7	10.47	1,256.6	8.73
16	50.26	4.189	201.06	1.396	41	128.8	10.73	1,320.3	9.17
17	53.41	4.451	226.98	1.576	42	131.9	10.99	1,385.4	9.62
18	56.55	4.712	254.47	1.767	43	135.1	11.26	1,452.2	[illegible]
19	59.69	4.974	283.53	1.969	44	138.2	11.52	1,520.5	10.56
20	62.83	5.236	314.16	2.182	45	141.4	11.78	1,590.4	11.04
21	65.97	5.498	346.36	2.405	46	144.5	12.04	1,661.9	11.54
22	69.11	5.760	380.13	2.640	47	147.7	12.30	1,734.9	12.05
23	72.26	6.021	415.48	2.885	48	150.8	12.57	1,809.6	12.57
24	75.40	6.283	452.39	3.142	49	153.9	12.83	1,885.7	13.10
25	78.54	6.545	490.87	3.409	50	157.1	13.09	1,963.5	13.61

ʟE 6.—Air volume, in cubic feet per minute, through supply pipes of various sizes at various velocities with corresponding friction losses of static pressure, in conventional inches of water

pe eter,	Velocity, feet per minute											
	2,000		2,400		2,800		3,200		3,600		4,000	
ı	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O
4	175	1.95	210	2.75	245	3.75	280	4.95	315	6.25	350	7.70
5	275	1.55	325	2.20	380	3.00	435	3.95	490	5.00	545	6.15
6	395	1.30	470	1.85	550	2.50	630	3.30	705	4.15	785	5.15
7	535	1.10	640	1.60	750	2.15	855	2.80	960	3.55	1,070	4.40
8	700	.95	840	1.40	975	1.90	1,120	2.45	1,260	3.10	1,395	3.85
.0	1,090	.75	1,310	1.00	1,530	1.50	1,750	1.95	1,965	2.50	2,185	3.10
.2	1,570	.65	1,885	.90	2,200	1.25	2,510	1.65	2,825	2.10	3,140	2.55
4	2,140	.55	2,565	.80	2,990	1.05	3,420	1.40	3,840	1.80	4,280	2.20
6	2,790	.48	3,350	.70	3,910	.95	4,470	1.25	5,025	1.55	5,580	1.90
8	3,540	.42	4,240	.60	4,950	.85	5,660	1.10	6,370	1.40	7,080	1.70
0	4,370	.38	5,230	.55	6,110	.75	6,980	1.00	7,860	1.25	8,740	1.55
2	5,280	.35	6,330	.50	7,390	.70	8,450	.90	9,500	1.15	10,560	1.40
4	6,280	.32	7,550	.46	8,800	.62	10,060	.80	11,320	1.05	12,560	1.30
0	9,820	.25	11,800	.36	13,760	.50	15,710	.65	17,700	.85	19,640	1.05
	4,400		4,800		5,200		5,600		6,000		7,000	
	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O	ft^3/min	inH_2O
4	385	9.25	420	11.05	455	13.00	490	15.25	525	17.30	610	23.60
5	600	7.40	655	8.85	710	10.50	765	12.05	820	13.85	955	18.90
6	865	6.20	945	7.40	1,020	8.65	1,100	10.05	1,175	11.50	1,375	15.65
7	1,175	5.30	1,285	6.30	1,390	7.45	1,495	8.60	1,605	9.90	1,875	13.50
8	1,535	4.65	1,675	5.55	1,820	6.50	1,955	7.55	2,095	8.65	2,445	11.80
[illegible]	2,400	3.70	2,620	4.45	2,840	5.20	3,060	6.05	3,275	6.90	3,820	9.40
[illegible]	3,455	3.10	3,770	3.70	4,080	4.35	4,400	5.05	4,710	5.75	5,500	7.80
[illegible]	4,700	2.65	5,130	3.15	5,560	3.70	5,980	4.30	6,420	4.95	7,470	6.75
[illegible]	6,140	2.35	6,700	2.75	7,260	3.25	7,820	3.80	8,360	4.35	9,770	5.90
[illegible]	7,780	2.05	8,480	2.45	9,200	2.90	9,900	3.35	10,620	3.85	12,380	5.25
[illegible]	9,620	1.85	10,460	2.20	11,360	2.60	12,220	3.00	13,100	3.45	15,300	4.70
[illegible]	11,620	1.70	12,660	2.00	13,740	2.35	14,780	2.75	15,820	3.15	18,480	4.25
[illegible]	13,840	1.55	15,100	1.85	16,360	2.15	17,600	2.50	18,860	2.90	22,000	3.95
[illegible]	21,620	1.25	23,600	1.50	25,560	1.75	27,520	2.00	29,440	2.30	34,400	3.15

Example 1.—Flat Storage

Design steps	*Example*
I. Establish storage specifications:	
A. Dimensions	60 ft wide, 140 ft long, 16 ft deep.
B. Type of loading	Flat, 16 ft deep.
C. Storage capacity:	
1. Floor area	60 ft $\times$ 140 ft = 8,400 ft^2.
2. Volume	8,400 ft^2 $\times$ 16 ft = 134,400 ft^3.
3. Capacity	134,400 ft^3 $\div$ 80 ft^3/ton = 1,680 tons.
II. Select type of system and airflow rate:	
A. Type of system	Fixed fan for each half-width of storage.
B. Design airflow rate	10 ft^3/min/ton.
III. Determine duct requirements:	
A. Total air volume	1,680 tons $\times$ 10 ft^3/min/ton = 16,800 ft^3/min.
B. Total duct surface area (duct surface air velocity, 10 ft/min)	16,800 ft^3/min $\div$ 10 ft/min = 1,680 ft^2.
C. Number of ducts (try 16)	1,680 ft^2 $\div$ 16 = 105 ft^2/duct.
D. Air volume per duct	16,800 ft^3/min $\div$ 16 ducts = 1,050 ft^3/duct/min.
E. Length of ducts	Try 22 ft.
F. Duct size	105 ft^2/duct $\div$ 22 ft/duct = 4.77 ft^2 lin ft.
G. Duct type (table 1)	Half-round, perforated.
H. Calculate cross-sectional area $\frac{\text{Air volume, ft}^3\text{/min}}{\text{air velocity, ft/min}}$	1,050 ft^3/min $\div$ 1,500 ft/min = 0.70 ft^2.
I. Aeration duct openings	3/32- to 3/16-inch round holes.
J. Duct material	16- or 18-gage sheet metal.
IV. Layout of ducts	Figure 31.
V. Determine supply pipe requirements (cross-sectional area based on air velocity of 1,500 ft/min—consult table 4):	
A. To connect duct to manifold	12-inch diameter.
B. Manifold, E section	16-inch diameter.
C. Manifold, F section	23-inch diameter.
VI. Determine fan and motor requirements:	
A. Air volume per fan	16,800 ft^3/min $\div$ 2 fans = 8,400 ft^3/min/fan.
B. Tons per fan	1,680 tons $\div$ 2 fans = 840 tons/fan.
C. Static pressure (fig. 27)	3.9 in H_2O.
D. Estimate power requirement (obtain hp/100 tons from fig. 27)	1.2 hp/per 100 tons $\times$ 8.4 = 10.08 hp/fan.
E. Select motor (check with fan manufacturer for efficiency and power requirements)	Use 10- or 15-hp motor.

Example 2.—Cottonseed Aeration System for Flat Storage With Partitions

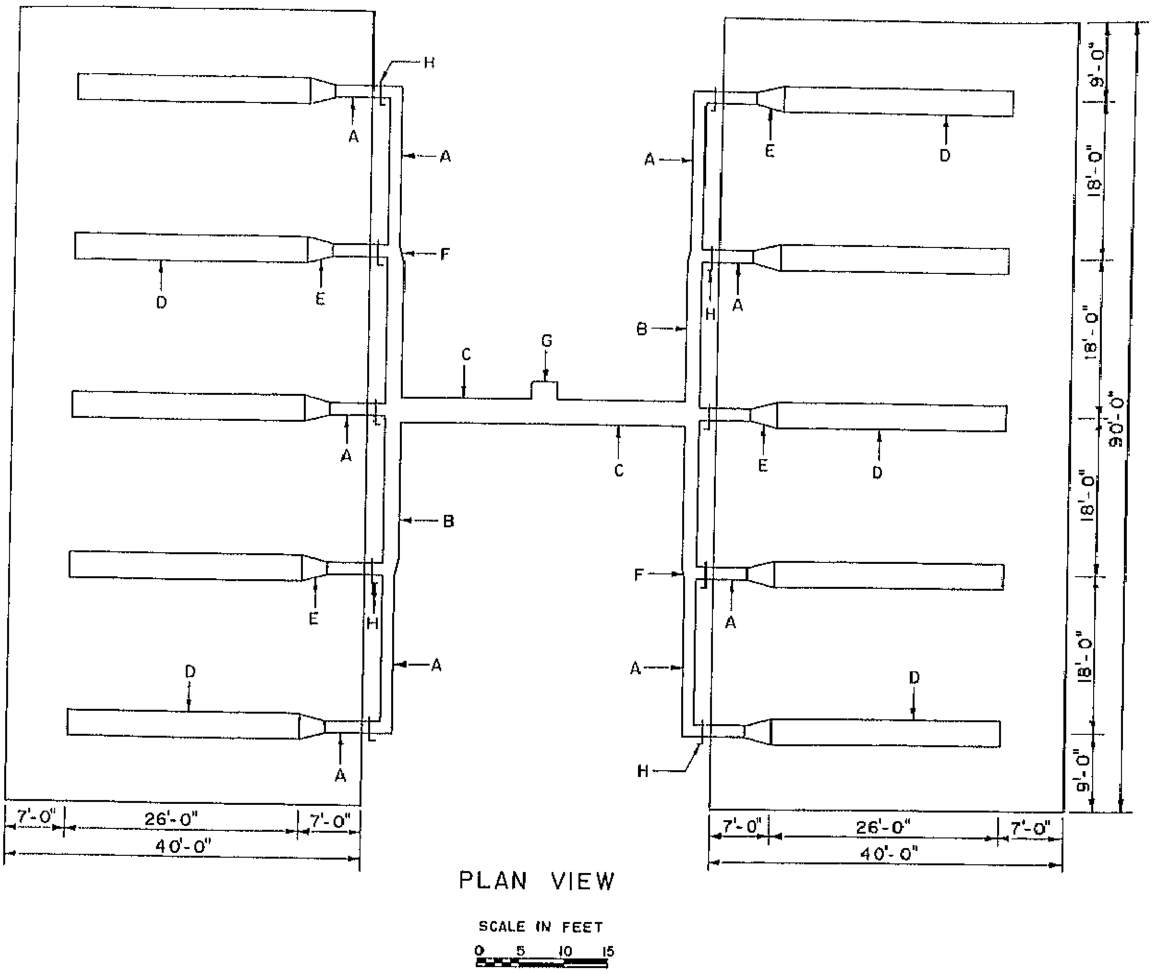
Design steps	*Example*
I. Establish storage specifications:	
A. Dimensions	40 ft wide, 80 ft long, 16-ft-high wall.
B. Type of loading	Flat, 14 ft deep.
C. Storage capacity:	
1. Floor area	2 bins, each 30×40 ft=1,200 ft^2. 1 bin, 20×40 ft=800 ft^2.
2. Volume	2 bins, 1,200 ft$^2\times14$ ft=16,800 ft^3. 1 bin, 800 ft$^2\times14$ ft=11,200 ft^3.
3. Capacity	2 bins, each 16,800 ft$^3\div80$ ft^3/ton=210 tons. 1 bin, 11,200 ft$^3\div80$ ft^3/ton=140 tons. Total capacity, 560 tons.
II. Select type of system and airflow rate:	
A. Type of system	1 fixed fan.
B. Design airflow rate	10 ft^3/min/ton.
III. Determine duct requirements:	
A. Air volume per bin	2 bins, each 210 tons$\times$10 ft^3/min/ton=2,100 ft^3/min. 1 bin, 140 tons$\times$10 ft^3/min/ton=1,400 ft^3/min. Total, 5,600 ft^3/min.
B. Duct surface area requirements (duct surface air velocity, 10 ft/min)	2 bins, each 2,100 ft^3/min$\div$10 ft/min=210 ft^2. 1 bin, 1,400 ft^3/min$\div$10 ft/min=140 ft^2.
C. Number of ducts required (try 2 ducts per bin)	2 bins, 210 ft$^2\div2$=105 ft^2/duct. 1 bin 140 ft$^2\div2$=70 ft^2/duct.
D. Length and size of each duct:	
1. For 2 bins, 30×40 ft	Try 26-ft length. 105 ft$^2\div26$ ft=4.04 ft^2/lin ft.
2. Duct size (for surface area, see table 3)	Half-round, perforated, corrugated steel, 30-inch diameter$\times$26 ft long.
3. Cross-sectional area $\dfrac{\text{air volume, ft}^3\text{/min}}{\text{air velocity, ft/min}}$	1,050 ft^3/min$\div$1,500 ft/min=0.70 ft^2.
4. For 1 bin, 20×40 ft	Try 22-ft length. 70 ft$^2\div22$ ft=3.18 ft^2/lin ft.
5. Duct size (for surface area, see table 3)	Half-round, perforated, corrugated steel, 24-inch diameter$\times$22 ft long.
6. Cross-sectional area $\dfrac{\text{air volume, ft}^3\text{/min}}{\text{air velocity, ft/min}}$	700 ft^3/min$\div$1,500 ft/min=0.47 ft^2.
E. Aeration duct opening	3/32- to 3/16-inch diameter round holes.
F. Strength of duct	18- to 20-gage.

Design steps	*Example*
IV. Layout of ducts	Figure 11.
V. Determine supply pipe requirements (cross-sectional area based on air velocity of 1,500 ft/min—consult table 4):	
A. To connect ducts to manifold	Large bin—12-inch diameter.
B. Manifold, D section	10-inch diameter.
C. Manifold, E section	12-inch diameter.
D. Manifold, F section	16-inch diameter.
VI. Determine fan and motor requirements:	
A. Total air volume	5,600 ft^3/min.
B. Total tons	560.
C. Static pressure (fig. 27)	3.0 inH_2O.
D. Estimate power requirements (obtain hp/100 tons from fig. 27)	0.95 hp/per 100 tons$\times$5.60=5.3 hp.
E. Select motor (check with fan manufacturer for efficiency and power requirements)	Use 7.5-hp motor.
VII. Determine opening for air entrance into storage:	
A. Provide opening with cross-sectional area twice that of supply pipe (equivalent of two 16-inch diameter supply pipes, table 5)	1.396 $ft^2\times2=2.792$ ft^2.
B. Continuous opening and protection from weather	Check before and during aeration.
VIII. Select controls:	
A. Magnetic motor starter	7.5-hp, line voltage.
B. Manual switches	3-pole, line voltage, fused or circuit breaker disconnect.
C. Automatic control system	Temperature and humidity controllers and elapsed time recorder.

Example 3.—Cottonseed Aeration System for Partially Peak-Loaded Storage

Design steps	*Example*
I. Establish storage specifications:	
A. Dimensions	2 storages, each 40 ft wide and 90 ft long, Quonset.
B. Type of loading	Semi-half-round, maximum depth, 14 ft.
C. Storage capacity:	
1. Floor area	40×90 ft=3,600 ft^2.
2. Volume	3,600 $ft^2\times14$ ft=50,400 ft^3 minus approximately 400 ft^3 for rounded sides.
3. Capacity	2 storages, each 50,400 $ft^3\div80$ ft^3/ton=625 tons. Total, 625 tons$\times$2=1,250 tons.

Design steps	*Example*
II. Select type of system and airflow rate:	
A. Type of system	1 fixed fan and motor for both storages (fig. 32).
B. Design airflow rate	15 ft^3/min/ton.
III. Determine duct requirements:	
A. Air volume per storage	625 tons×15 ft^3/min/ton=9,375 ft^3/min.
B. Total duct surface area per storage (duct surface air velocity, 15 ft/min)	9,375 ft^3/min÷15 ft/min=625 ft^2.
C. Number of ducts (try 5)	625 ft^2÷5 ducts=125 ft^2/duct.
D. Air volume per duct	9,375 ft^3/min÷5 ducts=1,875 ft^3/min/duct.
E. Length of ducts	Try 26 ft.
F. Duct size	125 ft^2÷26 ft=4.81 ft^2/lin ft.
G. Duct type (for surface area, see table 3)	Half-round, perforated, corrugated steel, 36-inch diameter, 26 ft long, plus perforated end plate.
H. Calculate cross-sectional area $\frac{\text{air volume, ft}^3\text{/min}}{\text{air velocity, ft/min}}$	1,875 ft^3/min÷1,500 ft/min=1.25 ft^2.
I. Aeration duct openings	3/32- to 3/16-inch round holes.
J. Strength of duct	20 gage.
IV. Layout of ducts	Figure 32.
V. Determine supply pipe requirements (cross-sectional area based on air velocity of 1,500 ft/min—consult table 4):	
A. To connect duct to manifold	16-inch diameter.
B. Manifold, B section	22-inch diameter.
C. Manifold, C section	34-inch diameter.
VI. Determine fan and motor requirements:	
A. Total air volume	18,750 ft^3/min.
B. Total tons	1,250 tons.
C. Static pressure (fig. 27)	4.90 inH_2O.
D. Estimate power requirements (obtain hp/100 tons from fig. 27)	2.0 hp/per 100 tons×12.5=25 hp.
E. Select motor (check with fan manufacturer for efficiency and power requirements)	Use 25-hp motor.
VII. Determine opening for air entrance into each storage:	
A. Provide opening with cross-sectional area twice that of supply pipes (equivalent of a 34-inch diameter supply pipe, table 5)	6.30 ft^2×2=12.60 ft^2.
B. Continuous opening and protection from weather	Check before and during aeration.
VIII. Select controls:	
A. Magnetic motor starter	25-hp, line voltage.
B. Manual switch	3-pole, line voltage, fused or circuit breaker disconnect.



Ⓐ 16" DIA. PIPE
Ⓑ 22" DIA. PIPE
Ⓒ 34" DIA. PIPE
Ⓓ 36" DIA. HR PERFORATED CORRUGATED AERATION DUCT OR EQUIVALENT
Ⓔ TRANSITION FROM 36" HR TO 16" DIA. PIPE
Ⓕ TRANSITION FOR DIFFERENT PIPE DIAMETERS
Ⓖ TO FIT FAN
Ⓗ SLIDE GATE

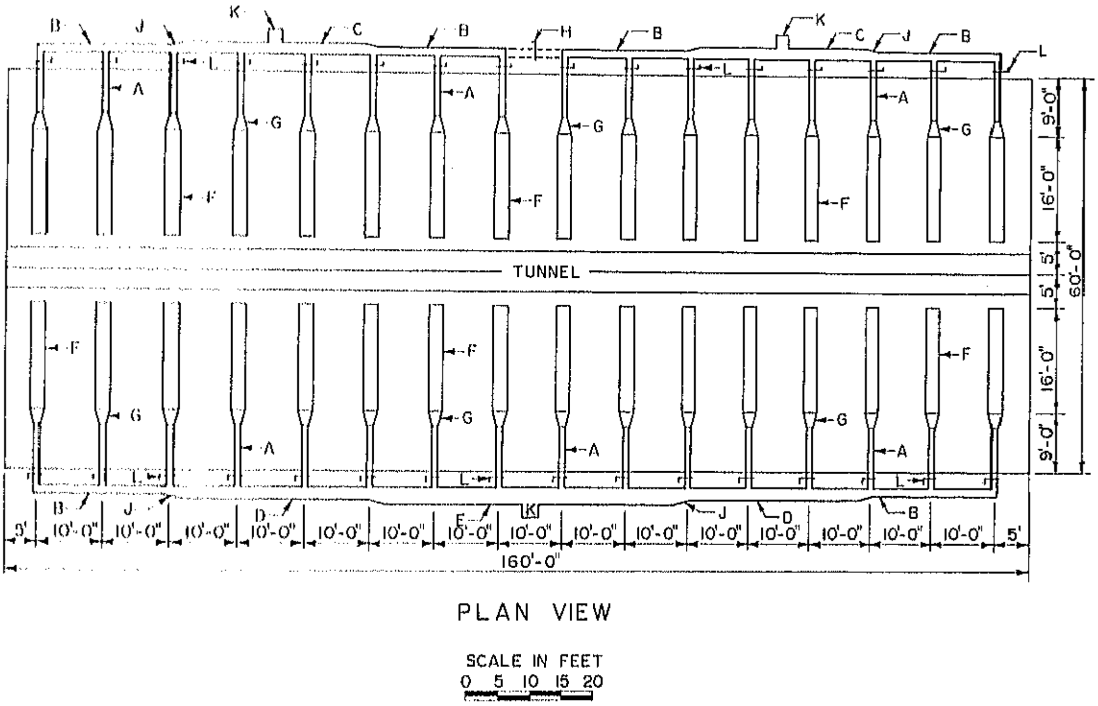
FIGURE 32.—Layout of aeration system for flat storage using one manifold and one fan.

Example 4.—Cottonseed Aeration System for Flat Storage, Peak-Loaded

Design steps	*Example*
I. Establish storage specifications:	
A. Dimensions	60 ft wide, 160 ft long, 12-ft-high wall.
B. Type of loading	Peak loading, 30 ft at peak. Full, 12 ft at sidewalls (fig. 33).
C. Storage capacity:	
1. Floor area	60 ft$\times$160 ft$=$9,600 ft^2.
2. Volume	$9{,}600\ \text{ft}^2\times 12\ \text{ft}+\frac{9{,}600\ \text{ft}^2\times 18\ \text{ft}}{2}=201{,}600\ \text{ft}^3$.
3. Capacity	201,600 ft$^3\div$75 ft^3/ton$=$2,690 tons.

Design steps	*Example*
II. Select type of system and airflow rate:	
A. Type of system	2 or 4 fixed fans (fig. 33).
B. Design airflow rate	10 ft^3/min/ton.
III. Determine duct requirements:	
A. Total air volume	2,690 tons × 10 ft^3/min/ton=26,900 ft^3/min.
B. Total duct surface area (duct surface air velocity, 15 ft/min)	26,900 ft^3/min÷15 ft/min=1,793 ft^2.
C. Number of ducts (try 16 each side, 32 total)	1,793 ft^2÷32 ducts=56.0 ft^2/duct.
D. Air volume per duct	26,900 ft^3/min÷32 ducts=841 ft^3/min/duct.
E. Length of ducts	Try 16 ft.
F. Duct size	56 ft^2÷16 ft=3.50 ft^2/lin ft.
G. Duct type (for surface area, see table 3)	Half-round, perforated, corrugated steel, 28-inch diameter × 16 ft long.
H. Tunnel sealed against air movement	Figure 18.
I. Calculate cross-sectional area $\frac{\text{air volume, ft}^3\text{/min}}{\text{air velocity, ft/min}}$	841 ft^3/min÷1,500 ft/min=0.56 ft^2.
J. Aeration duct openings	3/32- to 3/16-inch round holes.
K. Duct material	16- to 18-gage sheet metal.
IV. Layout of ducts	Figure 33.
V. Determine supply pipe requirements (cross-sectional area based on air velocity of 1,500 ft/min—consult table 4):	
A. To connect duct to manifold	12-inch diameter.
B. Manifold, B section (2-fan system)	15-inch diameter.
C. Manifold, D section (2-fan system)	23-inch diameter.
D. Manifold, E section (2-fan system)	29-inch diameter.
E. Manifold, C section (4-fan system)	21-inch diameter.
VI. Determine fan and motor requirements:	
A. Air volume per fan (2-fan system)	26,900 ft^3/min÷2=13,450 ft^3/min.
B. Tons per fan (2-fan system)	2,690 tons÷2=1,345 tons.
C. Air volume per fan (4-fan system)	26,900 ft^3/min÷4=6,725 ft^3/min.
D. Tons per fan (4-fan system)	2,690 tons÷4=673 tons.
E. Static pressure (use 25-ft depth, fig. 27)	10.50 inH_2O.
F. Estimate power requirements (obtain hp/100 tons from fig. 27):	
1. 2-fan system	3.0 hp/100 tons × 13.45=40.35 hp.
2. 4-fan system	3.0 hp/100 tons × 6.73=20.19 hp.
G. Select motor (check with fan manufacturers for efficiency and power requirements):	
1. 2-fan system	Use 40- or 45-hp motor.
2. 4-fan system	Use 20- or 25-hp motor.

Design steps	*Example*
VII. Determine opening for air entrance into storage:	
A. Provide opening with cross-sectional area twice that of supply pipes (equivalent of four 29-inch diameter supply pipes, table 5)	$4.59\ ft^2 \times 4 = 18.36\ ft^2$. $18.36\ ft^2 \times 2 = 36.72\ ft^2$.
B. Continuous opening and protection from weather	Check before and during aeration.
VIII. Select controls:	
A. Magnetic motor starters:	
1. 2-fan system	45-hp, line voltage.
2. 4-fan system	25-hp, line voltage.
B. Manual switches:	
1. 2-fan system	3-pole, line voltage, fused.
2. 4-fan system	3-pole, line voltage, fused.



Ⓐ 12" DIA. PIPE
Ⓑ 15" DIA. PIPE
Ⓒ 21" DIA. PIPE
Ⓓ 23" DIA. PIPE
Ⓔ 29" DIA. PIPE
Ⓕ 28" DIA. HR PERFORATED CORRUGATED AERATION DUCT OR EQUIVALENT
Ⓖ TRANSITION FROM 28" HR TO 12" DIA. PIPE
Ⓗ OPTIONAL PIPE CONNECTION WITH SLIDE GATE
Ⓙ TRANSITION FOR DIFFERENT PIPE DIAMETERS
Ⓚ TO FIT FAN
Ⓛ SLIDE GATE

FIGURE 33.—Layout of aeration system for peak-loaded storage using two manifolds connected to either two or four fans.

Example 5.—Cottonseed Aeration System for Muskogee-Type Storage, Peak-Loaded

Design steps	*Example*
I. Establish storage specifications:	
A. Dimensions	150 ft wide, 160 ft long, 25-ft-high wall.
B. Type of loading	Peaked. 95 ft at peak-full, 25 ft at sidewalls (fig. 34).
C. Storage capacity:	
1. Floor area	$150\ ft \times 160\ ft = 24,000\ ft^2$.
2. Volume	$(24,000\ ft^3 \times 25\ ft) + \frac{150\ ft \times 10\ ft \times 70\ ft}{2} + \frac{150\ ft \times 150\ ft \times 70\ ft}{3} = 1,177,000\ ft^3$.
3. Capacity	$1,177,000\ ft^3 \div 70\ ft^3/ton = 16,820$ tons.
II. Select type of system and airflow rate:	
A. Type of system	2 fixed fans and motors.
B. Design airflow rate	$2\ ft^3/min/ton$.
III. Determine duct requirements:	
A. Total air volume	$16,820\ tons \times 2\ ft^3/min/ton = 33,640\ ft^3/min$.
B. Total duct surface area (duct surface area velocity, 15 ft/min)	$33,640\ ft^3/min \div 15\ ft/min = 2,243\ ft^2$.
C. Aeration duct	2 central ducts—center 100 ft of each unloading tunnel.
1. Required surface area	$2,243\ ft^2$.
2. Surface area per linear foot of duct	$2,243\ ft^2 \div 200\ ft = 11.22\ ft^2/lin\ ft$.
3. Duct surface area provided	Pallets alongside of tunnel (fig 22) or tunnel covered with perforated sheet metal.
IV. System layout	Figure 34.
A. Portions of unloading tunnel sealed against air movement (approximately 35 ft)	Tunnel side doors, sheet plastic, or other sealing material (fig. 23).
B. Tunnel bulkhead doors	To close off parts of duct before storage is filled.
V. Determine supply pipe requirements (Cross-sectional area based on air velocity of 2,000 ft/min):	
A. Air volume per fan	$33,640\ ft^3/min \div 2 = 16,820\ ft^3/min$.
B. To connect tunnel duct to each fan (cross section)	$16,820\ ft^3/min \div 2,000\ ft/min = 8.41\ ft^2$.
C. Supply pipe size	40-inch-inside-diameter pipe or tile has cross section of $8.73\ ft^2$ (table 4).
VI. Determine fan and motor requirements:	
A. Air volume per fan	$16,820\ ft^3/min$.
B. Tons per fan	$16,820\ tons \div 2 = 8,410$ tons.
C. Static pressure (use 80-ft depth, fig. 28)	$20.5\ inH_2O$.
D. Estimate power requirements (obtain horsepower per 100 tons from fig. 28)	$1.4\ hp/per\ 100\ tons \times 84 = 117.0\ hp$.

Design steps	*Example*
E. Select motor (check with fan manufacturer for efficiency and power requirements)	Use 120 hp motor.
VII. Opening for air entrance into storage:	
A. Provide opening with cross-sectional area twice that of two 40-inch-diameter supply pipes (table 5)	8.73 ft^2×2=17.46 ft^2. 17.46 ft^2×2=34.92 ft^2
B. Continuous opening and protection from weather	Check before and during aeration.
VIII. Select controls:	
A. Magnetic motor starters	120-hp, line voltage.
B. Manual switches	3-pole, line voltage, fused.

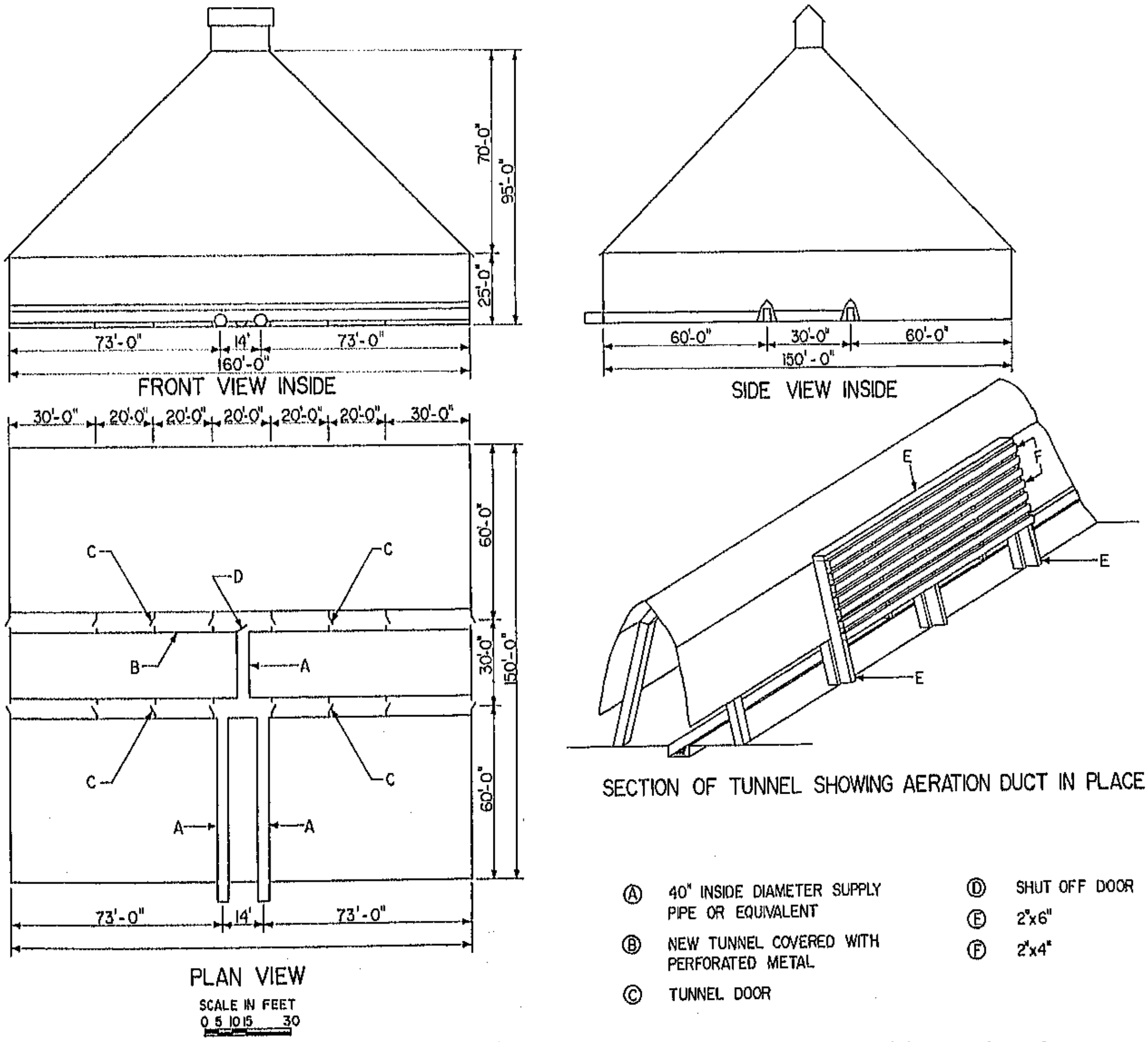


FIGURE 34.—Layout of aeration system for peak-loaded storage using two central ducts and two fans.